Three Gorges Water Control Project
Feasibility Study

People’s Republic of China

Volume 6
Navigation

March 1988

Sponsored by
Canadian International Development Agency

CIPM Yangtze Joint Venture
THREE GORGES PROJECT FEASIBILITY STUDY

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<td>CAAS</td>
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<td>CIDA</td>
<td>Canadian International Development Agency</td>
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<td>CPE</td>
<td>Chinese Panel of Experts (under leading group for Three Gorges Project studies)</td>
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<tr>
<td>Cs</td>
<td>Coefficient of Skewness</td>
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<td>Coefficient of Variation</td>
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<td>CYJV</td>
<td>CIPM—Yangtze Joint Venture</td>
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<td>CSICSC</td>
<td>China Statistical Information and Consultancy Service Center</td>
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<td>East China Electric Power Design Institute (China)</td>
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LIST OF ABBREVIATIONS (Cont’d.)

MCE — Maximum Credible Earthquake
MFL — Maximum Flood Control Operating Level
MOC — Ministry of Communications (China)
MOFERT — Ministry of Foreign Economic Relations and Trade (China)
Ms — Earthquake Magnitude as Indicated by the Surface Wave
MURCEP — Ministry of Urban and Rural Construction and Environmental Protection (China)
MWREP — Ministry of Water Resources and Electric Power (China)
NEPA — National Environmental Protection Agency (China)
NPL — Normal Pool Level
PDL — Power and Navigation Drawdown Limit
PMF — Probable Maximum Flood
PRC — People’s Republic of China
RCC — Roller Compacted Concrete
SF6 — Sulphur Hexafluoride (the gas used for insulating GIS)
TGPDC — Preparation Office for Three Gorges Project Development Corporation (China)
TGDEO — Three Gorges Economic Development Office (China)
TGM — Chinese Three Gorges mathematical model
TWL — Tail Water Level
UNDP — United Nations Development Program
USBR — United States Bureau of Reclamation
USCE — United States Corps of Engineers
YSRI — Yangtze Scientific Research Institute (China)
YVPO — Yangtze Valley Planning Office (China)
YWRPB — Yangtze Water Resources Protection Bureau (China)
ZEPDI — Zhongnan (South Central) Electric Power Design Institute (China)
GLOSSARY OF CHINESE TERMS

cheng/shi  city


cun  village

danwei  work unit

diqu  prefecture

he  river

hu  lake

jiang  river

jin  unit of weight  = 0.5 kg

mu  unit of area  = 0.067 ha

Sanxia  Three Gorges

xiang  township/county

yuan  monetary unit  = 0.3545 Canadian dollars
                      = 0.2703 U.S. dollars

DEFINITIONS

Requisition Level: Elevation below which compensation is paid for farmland, woodland, buildings and infrastructures in the reservoir study area. For most structures this level corresponds to NPL + 2 m or the 1:20 flood level, whichever is higher (Volume 9, Figure 5.1).

Relocation Level: Elevation above which people and structures are resettled. For most structures, this level corresponds to EL 182 for the CYJV Recommended Project or the 1:20 flood level, whichever is higher (Volume 9, Figure 5.1).

Steering Committee (SC): A committee established to oversee the feasibility study, assure its quality and provide overall direction to the Consultant and MWREP resources assigned to the conduct of the study. It consisted of nominees from MWREP, IBRD and CIDA plus eminent Chinese and international experts serving as ex-officio members.
I. BACKGROUND

The Chang Jiang or Yangtze, the largest river in China, carries nearly 40% of the country’s annual runoff. From the grassy plains of Qinghai province, the river flows eastward, cutting through successive mountain ranges and ridges before meandering across the Central China plains.

The Three Gorges Water Control Project, located near the mouth of the Three Gorges, can provide flood protection to approximately 1 million km² in the middle reaches of the Yangtze Valley, generate a large amount of hydroelectric power and improve navigation in the Yangtze River between Chongqing and Shanghai. It involves construction of a dam, about 175 m high, at Sandouping in the middle section of the Xiling Gorge, 40 km upstream of Yichang and the relocation of a large population from the affected reservoir area.

In 1983, the Yangtze Valley Planning Office, an agency of the Ministry of Water Resources and Electric Power prepared a feasibility report for the Three Gorges Project, with a dam crest level of 165 m, a Normal Pool Level of 150 m, an installed generating capacity of 13,000 MW and permanent navigation locks adequate to pass 10,000 t tows. It was subsequently approved by the State Council of the People’s Republic of China with the provision that the dam crest be increased to 175 m. In March 1985, a Preliminary Design Report for this project was completed.

Requests were made by the Ministry of Communications (MOC) and the city of Chongqing, that levels be raised to further improve navigation. In March 1986, the Ministry of Water Resources and Electric Power (MWREP) prepared a revised report recommending a Normal Pool Level of 160 m, a dam crest level of 175 m, and an installed generating capacity of 14,800 MW, other features remaining unchanged.

A number of detailed investigations on various aspects of the project have been continued since 1983, including engineering, sedimentation, landslides, environmental impact, resettlement, power planning, construction planning and cost estimating.
II. PURPOSE OF THE FEASIBILITY STUDY

The purpose of the Feasibility Study is to evaluate on a basis acceptable to international financial institutions, the technical and economic feasibility of the Three Gorges Project and the viability of the financial investment.

For this purpose the Ministry of Water Resources and Electric Power and the Canadian International Development Agency engaged CIPM Yangtze Joint Venture to prepare a Feasibility Report that would provide an impartial technical input to the Government of China in its decision-making process, and could form a basis for securing funding from international institutions.

The Feasibility Report was to be comprehensive, covering costs and benefits of the main aspects of flood control, power generation and transmission, navigation, resettlement and environment. The Report was to assess whether the Project represents the least cost solution for deriving the planned benefits and how project features have been optimized. For this Study, CIPM Yangtze Joint Venture was requested to study a full range of schemes defined by four normal pool levels at El 150, 160, 170, and 180. This range of levels primarily affects the project operation, the extent of resettlement, and the benefits for flood control, power and navigation.

III. ORGANIZATION OF THE FEASIBILITY REPORT

The results of the Feasibility Study are presented in an Executive Summary and 11 Volumes as listed below. Volumes 1 and 3 are general volumes dealing with the entire project. Volume 2 is a general volume providing the construction cost estimate and schedule. Volumes 4 through 11 are supporting volumes, each dealing with its designated subject.

The list of volumes is as follows:

General Volumes:

   Executive Summary
1. Feasibility Report
2. Construction Planning, Scheduling and Estimating
3. Economic and Financial
Supporting Volumes:

4. Design
5. Sediment
6. Navigation
7. Flood Control
8. Environment
9. Resettlement
10. Power Benefits
11. Regional Economic Impacts.

IV. BASIC DEFINITIONS FOR THE FEASIBILITY REPORT

A number of concepts and assumptions which are common throughout the study are presented below.

Operating Water Levels:

— Winter Dry Season

During October, at the end of the wet season, the reservoir will be filled to Normal Pool Level. This is the highest normal operating level of the reservoir. Water levels will be maintained at Normal Pool Level until stored water is needed during critical dry periods to increase outflows for navigation and power.

In winter, the lowest level of drawdown which will occur only occasionally, is called the Power and Navigation Drawdown Limit. Winter operating storage is defined as the volume between Normal Pool Level and Power and Navigation Drawdown Limit.

During the winter season, the power plant will operate at full head when at the Normal Pool Level but with reduced output depending on the dry season inflows. Daily peaking operations will be possible with reregulation in the Gezhouba reservoir to ensure steady flows downstream.

— Summer Flood Season

During the month of May, power generation is increased to draw down the reservoir to its Flood Control Level for sediment control and increased flood storage. This is the lowest normal operating level of the reservoir.
in the period June through September. During this period, reservoir inflows are used for power generation while attempting to hold the reservoir at the Flood Control Level. Excess inflows are released to flush sediment through the reservoir and past the structures by means of sediment flushing outlets and submerged spillway bays.

Flood control storage is provided above the Flood Control Level. For moderate floods, up to the 1:50 year occurrence, flood control is provided without the reservoir exceeding the Normal Pool Level. For greater floods, levels will rise higher depending on the magnitude of the inflows.

Development Dates:

The following schedule dates were assumed:

- Government of China decision to proceed July 1988
- Start of construction support facilities and Year 1 of Project schedule January 1989
- Approval of Stage 1 Construction January 1990
- Start of Construction, Stage I Cofferdam October 1990
- Start of Resettlement January 1991
- First power on line, Units No. 1 & 2 August 2000
- Completion of Resettlement January 2003
- Completion of last unit December 2006

Costs and Benefits:

All costs and benefits in the report are calculated at January 1987 price levels. Net present values of annual cost and benefit streams are computed using a discount rate of 10% per annum.
V. DESCRIPTION OF THE RECOMMENDED PROJECT

The recommended project which results from this Feasibility Study consists of:

- **A Concrete Gravity Dam** 2.5 km long with crest level at EI 185. The dam is made up of a central spillway flanked by gravity dams on each side.

- **Navigation Structures** on the left bank made up of a single temporary lock and twin five-flight locks as permanent facilities.

- **Two Powerhouses** downstream of the left and right bank intake blocks. Each powerhouse has 11 units and 2 service bays.

And is based on:

- **Reservoir Land Requisition Level** – the 1:20-year flood level for permanent residences and the 1:100-year flood level for large factories. All displaced structures are to be relocated above EI 182, which corresponds with the 1:1000-year flood level at the dam.

- **Resettlement Planning Criteria** which improve living conditions of the affected population ("resettlement with development").

- **Environmental Planning Criteria** which protect rare and endangered species and provide improved facilities to mitigate other effects.

Salient data for the recommended project are given below.

**SALIENT DATA FOR CYJV RECOMMENDED PROJECT**

<table>
<thead>
<tr>
<th>1. Reservoir Data and Discharges</th>
<th>Elevation (m)</th>
<th>Volume (m³)</th>
<th>Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Pool Level (NPL)</td>
<td>160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flood Control Level (FCL)</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power and Navigation Drawdown</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limit (PDL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Flood Control Operating</td>
<td>181</td>
<td>80 000</td>
<td></td>
</tr>
<tr>
<td>Level (MFL) and Discharge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check Flood Level (PMF) and</td>
<td>183</td>
<td>116 000</td>
<td></td>
</tr>
<tr>
<td>Discharge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Storage</td>
<td></td>
<td>48.1 x 10⁹</td>
<td></td>
</tr>
<tr>
<td>Flood Control Storage</td>
<td></td>
<td>31.0 x 10⁹</td>
<td></td>
</tr>
<tr>
<td>Average Annual Runoff Volume</td>
<td></td>
<td>451 x 10⁹</td>
<td></td>
</tr>
<tr>
<td>Average Annual Discharge</td>
<td></td>
<td>14 300</td>
<td></td>
</tr>
<tr>
<td>Regulated Discharge during Dry Season</td>
<td></td>
<td>5 120</td>
<td></td>
</tr>
</tbody>
</table>
2. **Project Effects**

Flood Protection Provided for Downstream Area:

- 1:100—year flood, without diversion into Jingjiang Region, water level at Shashi not to exceed El 44.5.

- 1:1000—year flood, with diversion into Jingjiang Region, water level at Shashi not to exceed El 45.0.

Flood Protection Provided for the Reservoir Area:

- to El 160: 1:45 year flood

- to El 181: 1:1 700 year flood

<table>
<thead>
<tr>
<th>Total Installed Capacity</th>
<th>16 750 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long—term Average Annual Energy</td>
<td>76.2 TWh</td>
</tr>
<tr>
<td>Improved Navigation Distance in the Reservoir</td>
<td>500—600 km</td>
</tr>
<tr>
<td>Inundated Cultivated Land</td>
<td>300 000 mu (20 000 ha)</td>
</tr>
<tr>
<td>Affected Population to be Resettled to above El 182.</td>
<td>727 000</td>
</tr>
<tr>
<td>Length of roads and highways to be relocated</td>
<td>650 km</td>
</tr>
<tr>
<td>County seats affected</td>
<td>11</td>
</tr>
<tr>
<td>Towns affected</td>
<td>104</td>
</tr>
</tbody>
</table>

3. **Main Structures and Facilities**

Concrete gravity intake dam and spillway:

<table>
<thead>
<tr>
<th>Crest Elevation</th>
<th>185 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Height</td>
<td>175 m</td>
</tr>
<tr>
<td>Crest Length</td>
<td>2 150 m</td>
</tr>
<tr>
<td>Submerged Spillway Bays</td>
<td>27 — 7 m wide x 9 m high</td>
</tr>
<tr>
<td>Overflow Bays</td>
<td>26 — 8 m wide</td>
</tr>
</tbody>
</table>

Powerhouses:

- Left Powerhouse: 11 units at 761 MW
- Right Powerhouse: 11 units at 761 MW
- Turbines — NominalRated Output: 695 MW
- Generators — Nominal Rated: 845 MVA at 0.9 power
- Capacity factor: 3 single phase/unit
- Main Transformers: 500 kV, Metal clad
- Switchyard: SF6 GIS
Transmission
Temporary Navigation Lock
Permanent Navigation Locks

12 circuits, 500 kV AC
Single stage 33 m maximum lift
Twin five stage flight locks, 20 m lift per stage

4. Construction Work

Excavation
Embarkment fill (soil and rock)
Plain and Reinforced Concrete
Steel Reinforcement
Structural Steel
Total Time of Construction
Construction Time to First Generation

87 100 000 m³
34 100 000 m³
25 300 000 m³
290 000 t
210 000 t
18 years
140 months (11.7 yr)

5. Manpower Requirements

Total manpower for construction, manufacturing and material supply

942 000 man yr
1. SUMMARY

1.1 Introduction

The interrelationships between the proposed Three Gorges Project and navigation on the Yangtze River are an important aspect of the project's design and feasibility. The short and long-term effects of the project have been carefully examined in the feasibility study. This volume describes the various effects of the project on navigation conditions and on economic impacts for a range of project design and operating scenarios.

Navigation benefits are determined from analysis of present and future operations of navigation on the Yangtze up to Chongqing, both with and without Three Gorges Project. Traffic demand, capacity of facilities, cost-effectiveness of structures and their effect on navigation are discussed for each stage of project development. The technical viability of the proposed designs for temporary and permanent navigation facilities and of certain structural modifications are discussed in Volume 4 of this report, Design.

1.2 Highlights of Findings

1.2.1 General

The development of Three Gorges Project will create a completely new environment for navigation on the Upper Reach of the Yangtze. In most instances the changes are beneficial, as the impounding of a deep reservoir behind the dam creates more consistent and less restrictive navigation conditions. These in turn lead to potential improvements both in costs and in the capacity to move water-borne traffic on the river.

The value of these improvements depends on several factors including:

- the degree of improvement relative to existing and probable future conditions without Three Gorges Project;
- the amount of future traffic which potentially benefits from improved conditions; and
- the capacity of the system to handle this future demand and hence the share of potential cost savings which can be realized.

All of these issues have been reviewed in the navigation studies and, in most cases resolved through a combination of independent analysis and consultation with the various Chinese ministries. The one unresolved issue is the forecast of future traffic, where Chinese estimates are significantly higher than those which CYJIV is able to support on the basis of available data. Because the forecasts could not be reconciled, navigation was evaluated for a range of future traffic levels.
There is clearly scope, however, for further study of potential traffic on the river, especially since impacts and benefits are highly sensitive to the assumed future demand. Studies should include detailed data collection regarding the nature, origins and destinations of existing commodity movements, both water and land—based, and a careful definition and assessment of future sources of traffic demand. Further analysis of potential passenger traffic would also be useful. This would involve development of data regarding existing market segments including domestic and foreign tourism, inter—city movements and local movements to regional centres which would assist in forecasting expected growth rates.

1.2.2 Existing Navigation Conditions

At the present time, shipping through the Upper Reach of the river between Yichang and Chongqing is constrained by hazardous conditions and limited capacity. High velocities, narrow channels, shallow depths, and sharp bends limit barge and tow sizes, and impose further cost penalties due to restricted operating hours and delays in transiting one—way and winching sections. As a result, the cost of shipping through the Upper Reach of the river is more than double the cost incurred in the sections below Yichang.

Maintaining and operating the river channel also involves fairly substantial efforts and expenditures. Costs include the manning and operation of winching stations, staffing and operation of one—way control stations, maintenance and tending of numerous channel markers and other navigation aids, and an ongoing program of dredging and excavation in order to maintain required widths and depths in the channel.

1.2.3 Future Navigation Without Three Gorges Project

While there is some potential to improve navigation conditions and reduce costs in the Upper Reach without Three Gorges Project, through better operating procedures, modified equipment design and continued excavation and river training projects, it is not possible to completely overcome the effects of the river morphology. It is difficult to control velocities through steep gorges and over shallow sections and shoals, while narrow channels and sharp bends can only be remedied by major excavation efforts. Without Three Gorges Project, future navigation will therefore likely continue to be constrained by high velocities and one—way channels in many sections of the Upper Reach, and it will be difficult to attain a level of cost and capacity which would attract a significantly higher share of traffic to the river mode.
1.2.4 Navigation During Construction of the Project

If construction of Three Gorges Project proceeds, navigation on the river will be affected only to a limited extent during the construction period. Conditions in the Upper Reach of the river will not change significantly until the reservoir is impounded, mid-way through the 12th year of the construction schedule. Conditions around the construction site will be affected as sections of the river are cofferdamed. However, the facilities proposed by YVPO to handle navigation during this period, including the diversion channel, temporary lock and shiplift, offer adequate capacity to meet forecast demand with the fleet mix expected during that time.

The question of the need for, and cost-effectiveness of the shiplift at this stage of the project was also raised and reviewed. It was found that, with the exception of an estimated 4 – 6 week period when the reservoir is being raised, the channel and temporary lock should be able to meet traffic demand. During the 4 – 6 week closure, the shiplift would provide some ongoing navigation. However, its dimensions restrict its capacity to handle large tows, and its usefulness is therefore somewhat limited.

Eliminating or deferring the shiplift would involve suspending navigation during the closure period and finding alternative means of meeting demand, either via other modes or by stockpiling. However, the capital and operating costs saved by omitting the shiplift would more than offset the cost of the alternatives.

1.2.5 Future Navigation With Three Gorges Project

Once the Three Gorges reservoir is impounded, there will be a substantial change in navigation conditions. At the Project site, vessels will be routed through the proposed locks.

Navigation conditions will also change substantially on the river above the dam, with wider, deeper channels and lower velocities throughout the reservoir. The reservoir length is also sufficient, over the range of scenarios evaluated, to permit elimination of all winching stations and many of the one-way control sections.

The Project will also lead to improved navigation conditions in the river downstream of Yichang as higher flows in the dry season alleviate depth problems in some areas. However, dry season flows will also be improved as a result of other planned projects which are further upstream and, as such, the benefit is only partly attributable to Three Gorges Project.

The navigation sector benefits from the improved river conditions above Yichang in a number of ways. Larger tows can be brought into service, delays at one-way and winching sections will decline, daily operating hours can be extended through most reaches of the river, and upbound capacities and fuel consumption will improve due to reduced channel velocities, although the latter will be partially offset by either increased fuel
consumption or longer sailing times for downbound traffic. These factors together will lead to lower operating costs and increased carrying capacity, through larger units and additional transits, on the river.

While these improvements will apply over a large section of the Upper Reach in reservoir scenarios, there are some important differences among them, specifically in the length of the reservoir and hence the portion of the river which remains in natural conditions. These differences affect the costs of navigation and the capacity of the river channel.

.1 Effect of NPL

In general, higher reservoir levels lead to reduced navigation costs and increased capacity. During the dry season, at NPL 150, the river remains in its natural state for roughly 60 km below Chongqing and at least two sections will have to be operated one-way throughout most of the dry season. At NPL 160, reservoir conditions extend almost to Chongqing, but at least one section will be constrained during part of the dry period. With an NPL of 170 m, the reservoir will extend well upstream of Chongqing and hence most of the traffic will be moving in reservoir conditions. Raising the reservoir to 180 m would not add significant benefits in transportation cost savings. It could, however, reduce the risk that reservoir levels would be pulled down below critical limits during the dry season.

.2 Effect of FCL

The various proposed FCLs also result in different reservoir lengths and hence in navigation costs. However, under all FCLs considered, operations will continue to be constrained through at least two sections of the channel — Tongluoxia and Huangcaxia. Flood season capacity of the river will be limited by one-way channels and reduced tow sizes through these sections.

.3 Capacity of the System

Future capacity of the navigation facilities and the river channel above Yichang depends on the mix of traffic using the river. The future fleet composition will depend in turn on the growth in passenger and freight traffic and on the extent to which new vessel types are introduced in response to changing demand and conditions. One possible range of future fleet mixes was selected for evaluation from both a cost and capacity perspective. The proposed fleets varied according to the forecast demand, with an increasing share of large tows assumed as forecast traffic levels increase. While these fleet mixes represent one manner in which the fleet might logically evolve over time in response to the changing traffic and navigation conditions, they are not intended to represent optimal vessel specifications either in terms of maximizing system throughput or minimizing cost.
Over the range of fleet mixes evaluated, capacity of the reservoir, lock and river system was limited by the permanent navigation facilities at Three Gorges. One-way annual capacities through the locks range from a low of $27 \times 10^6$ tonnes with a large number of small tows and passenger vessels in the fleet, to a high of $38 \times 10^6$ tonnes with primarily $9 \times 1000$ tonne tows and no passenger movements. With the locks and shiplift together, capacities range from a low of $33 \times 10^6$ tonnes to a high of $41 \times 10^6$.

Neither of these capacities is sufficient to meet the demand of $50 \times 10^6$ tonnes forecast by the YVPO and the MOC. To meet this demand, the average lockage would have to carry between 9 000 and 11 000 tonnes. Achieving this average would require a much greater degree of fleet optimization than has been projected in the analysis, including a substantial shift to higher-capacity barges and strong policy steps to limit the number of small vessels on the river. If these steps can be accomplished, significantly higher lock capacities could be achieved and the channel upstream of the Project would become the limiting factor in system capacity.

4 Channel Maintenance and Operations

The development of Three Gorges will also affect the costs of channel maintenance and operation in the Upper Reach of the river. Most of the costs of operating winching stations and one-way control stations will be eliminated, and the effort required to maintain and adjust channel markers should be reduced. In addition, there will likely be a reduction in the amount of excavation and dredging work both in the Upper Reach and below Gezhouba. Some of these savings will be offset by the sediment effects of the project, particularly the deposition of gravel in the variable backwater reach of the reservoir and of finer material at the lock approaches. Annual dredging may be required to maintain the navigation channel at both these locations.

1.2.6 Navigation—Related Benefits

The benefits of improved navigation on the Upper Reach of the river were calculated by comparing, on a net present value basis, the total costs of moving passengers and freight through the Upper Yangtze corridor without Three Gorges with the total costs if the Project is built. The analysis examined the costs of both water and overland transport, the probable modal splits with and without Three Gorges Project, and the resultant costs of moving freight and passengers through the region. The analysis also examined the costs of maintaining the navigation channel with and without the project, an issue closely related to questions of sedimentation.

As a base case, the capacity of the system with Three Gorges was limited by the capacity of the permanent locks assuming 12 passenger vessel transits per day. The capacity of the natural river without Three Gorges
Project was based on a similar number of passenger vessel transits and a fairly optimistic shift towards maximum-size, 3 x 1 000 tonne tows in the fleet mix. Several sensitivity studies were carried out to examine the impact of alternative assumptions regarding the capacity of the system with and without Three Gorges, and also the impact of a shift in the fleet mix towards higher-capacity barges.

1 Transportation Cost Savings

Total savings in transportation costs (the costs of moving passengers and freight through the region) are shown for the base case assumptions in the table below.

**TRANSPORTATION COST SAVINGS — BASE CASE**
*(Net Present Value — yuan x 10⁶)*

<table>
<thead>
<tr>
<th>Reservoir Level (NPL/FCL/PDL)</th>
<th>Low Traffic</th>
<th>Medium Traffic</th>
<th>High Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>150/135/130</td>
<td>435</td>
<td>732</td>
<td>1 398</td>
</tr>
<tr>
<td>160/135/145</td>
<td>449</td>
<td>757</td>
<td>1 442</td>
</tr>
<tr>
<td>160/140/140</td>
<td>454</td>
<td>767</td>
<td>1 456</td>
</tr>
<tr>
<td>170/140/150</td>
<td>466</td>
<td>788</td>
<td>1 495</td>
</tr>
<tr>
<td>170/145/150</td>
<td>475</td>
<td>803</td>
<td>1 522</td>
</tr>
<tr>
<td>180/150/165</td>
<td>479</td>
<td>810</td>
<td>1 533</td>
</tr>
</tbody>
</table>

2 Channel Maintenance Costs

A small saving in channel maintenance costs is expected as a result of the project. While additional annual dredging will be required to remove coarse sediment deposits and maintain navigation depths, the projected increase in dredging costs is less than the savings realized by elimination of winching, reductions in one-way sections, and reductions in the costs of maintaining navigation aids. The present value of the anticipated saving is 14.3 x 10⁶ yuan.

3 Sensitivities

If a higher capacity is assumed for the navigation facilities, either due to greater tonnes per lockage or shorter cycle times, the capacity of the river system with Three Gorges may be constrained by the upstream channel rather than the navigation facilities. Transportation cost savings under these conditions are virtually unchanged from the base case for the Low and Medium forecast traffic levels.

With the High traffic forecast, an assumed increase in system capacity results in a 9% increase in savings for the NPL 150 reservoir scheme and an 11% increase for the higher reservoir scenarios.
However, if the system capacity without Three Gorges is also assumed to be higher than in the base case, net savings for the high traffic forecast decline.

If increased system capacity with Three Gorges is combined with a shift to higher capacity barges, the associated reduction in vessel operating costs, would provide an additional 4 to 6.5% saving in total transportation costs.

1.3 Conclusions

- The facilities which YVPO has proposed to handle navigation both during construction of the project and after it is in operation are adequate to meet the capacity and operating requirements of the navigation sector.

- Notwithstanding the above, some modifications to the proposed design would appear to be cost-effective. In particular, eliminating the shiplift from both the temporary and permanent designs would lead to significant net cost savings.

- A system of twin five-stage flight locks is recommended for the permanent navigation facilities. Twin separate locks with intervening channels would be more costly to construct in one stage and could interfere with construction of the dam and powerhouse facilities.

- The separate lock system would be less costly if it were built in two stages, and if demand growth were low enough to allow the second stage to be deferred for at least 6 years based on a 10% discount rate. However, given the existing traffic data base, it is not possible to predict with any degree of confidence whether or not staged construction may be cost-effective. Consequently, at this time, the twin flight-locks scheme is recommended.

- The project will create a deep reservoir over most of the reach between Yichang and Chongqing, lowering stream velocities during both dry and flood season. Most navigation constraints on this part of the river will be eliminated.

- With the project, costs of transportation on the river will decline and capacities will increase, leading to overall reductions in the costs of moving freight and passengers through the Upper Yangtze corridor.
The longer reservoir associated with higher pool levels will generate greater transportation cost savings. However, since most of the reach to Chongqing is improved in all of the scenarios which were assessed, percentage differences are fairly small. Total transportation cost savings increase by approximately 10% when the pool levels are raised from 150/135 to 180/150.

Costs of operating and maintaining the river channel will decline as a result of the project, although the savings in winching, operation of one-way sections and maintenance of navigation aids will be partly offset by the dredging required to remove gravel deposits in the fluctuating backwater section.

The value of benefits related to improved navigation is highly sensitive to the future demand for transportation through the corridor. With the medium traffic forecasts, transportation cost savings range from 732 x 10^6 yuan at NPL 150 to 810 x 10^6 yuan at NPL 180. With the low traffic forecasts, savings range from 435 to 479 x 10^6 yuan, while with the high forecasts proposed by YYPO/MOC, they range from 1 398 to 1 533 x 10^6 yuan.

The level of benefits is relatively insensitive to the potential range of river system transportation capacities. Even with the high traffic forecast, a 50% increase in the capacity of the system with Three Gorges generates a 10% increase in transportation cost savings. If increased system capacity is combined with a shift towards larger or higher capacity barges, an additional 4 to 6.5% saving is achieved.

The inter-relationships between the Three Gorges Project and the navigation sector on the Upper Yangtze river are extensive and complex. The project will materially affect the future navigation conditions on the river, generally to the benefit of the users.

While the benefits as measured in this study increase with higher NPL/FCL levels, these increases are small in relation to total navigation benefits. However, the analysis did not attempt to optimize navigation to each water level and traffic scenario. If fleets and operations were optimised to the different reservoir levels and forecast demands, differences between scenarios might be greater.

While the economic analysis indicates that navigation will benefit as a result of the creation of the Three Gorges reservoir, the predicted benefits are based on the presumption that reservoir operating procedures will reflect the requirements of the navigation sector. The operating rules adopted with regard to the timing of transitions between NPL and FCL (including the rate of change and the flow conditions in the river) and the rules established with regard to timing and duration of controlled flows
through the power plant can all affect, on a temporary basis, navigation on the river. In establishing the day-to-day operating rules for the reservoir, it will therefore be necessary for the project operators to be sensitive to these potential impacts if Three Gorges is to successfully fill its role as a multi-purpose project.
2. INTRODUCTION

The interrelationships between navigation on the Yangtze River and the proposed Three Gorges Project play an important role in determining both the project's design and its feasibility. The short and long-term effects of the project on navigation, in terms of the physical operating environment which it creates and the economic impact which this will have on water-borne transport through the Region, are an integral part of several aspects of the feasibility study including facilities design, studies of reservoir operating procedures, and the assessment of the Project's economic viability.

This volume draws together these various aspects of the study as they relate to navigation, and provides a comprehensive picture of both the physical and economic impacts, including navigation-related benefits, under a range of Project design and operating scenarios.

2.1 Objectives of Navigation Studies

The specific objectives relating to navigation in the feasibility studies were threefold:

- evaluate the technical viability of the proposed designs for temporary and permanent navigation facilities and assess certain structural modifications;

- review the proposed operation of the navigation facilities and assess the adequacy of capacity; and

- assess the economic benefits associated with improved navigation through the Upper Yangtze Corridor under alternative Three Gorges Project operating schemes.

The above studies involved, to a large extent, a review and assessment of detailed work already carried out by YVPO. In some areas, modified concepts for design and operation were defined and evaluated. In other areas, most notably the assessment of navigation benefits, the work previously carried out by the Chinese was used as a basis for developing a wider-ranging evaluation process which could be integrated into the overall statement of project feasibility.

This volume focuses on the studies relating to the second and third navigation objectives: the review of operations and capacity and the assessment of economic benefits. These two study areas have been grouped together both because they are closely inter-related and because they are based on common assumptions regarding current and future traffic, channel conditions, vessel types, fleet mix, etc. The studies relating to the design of temporary and permanent navigation facilities, however, are only covered in general terms in this volume. Details of
these studies, together with other Project design issues, are provided in Volume 4 of this Report.

2.2 Organization of Volume 6, Navigation

The navigation volume is structured to describe the probable short-term and long-term changes in navigation on the Upper Yangtze, both with and without Three Gorges Project. Sections 3 and 4 describe the present-day navigation conditions on the Upper Yangtze and discuss the way in which these conditions are likely to change over time without Three Gorges Project. Sections 5, 6 and 7 deal with conditions which might be expected if Three Gorges Project is constructed. Section 5 discusses conditions during the construction period while Sections 6 and 7 describe conditions in the long-term under various reservoir operating scenarios. Each section also discusses traffic demand, operations, cost and capacity in the context of the changing conditions.

Section 8 describes the economic implications of the changes in navigation conditions resulting from construction of Three Gorges Project and provides measures of the Project's benefits to the navigation sector. Finally, Section 9 provides a brief summary of the findings of the navigation studies and highlights the main conclusions regarding the Project's impact on navigation. A number of technical Appendices are also attached covering detailed aspects of traffic forecasting, vessel costing, and channel capacity.
3. CURRENT STATUS OF NAVIGATION ON THE YANGTZE RIVER

3.1 Introduction

The Yangtze River is one of three key inland waterways in China. From headwaters in the Xizang—Qinghai plateaus, the Yangtze flows 6300 km through nine provinces before discharging into the East China Sea at Shanghai (Plates 6.1 and 6.2). With a total drop of 5400 metres, an annual runoff at the sea of $1.0 \times 10^{12}$ m³, and a navigable length, including tributaries, of 70000 km,¹ the Yangtze is regarded as an important part of China’s hydro-electric resources and of her inland water transportation network.

Generally, the head of commercial navigation on the Yangtze is considered to be at Yibin in Sichuan Province where the Minjiang and Jingshajiang join together and the Changjiang reach of the river begins. Yibin lies some 400 km upstream of Chongqing, 2800 km from Shanghai. From Yibin to Fengjie some 440 km downstream of Chongqing, the river flows through a series of moderately deep valleys before entering the Three Gorges Region, which extends a further 200 km to Yichang in Hubei Province. Within the Yibin—Yichang reach, the main river serves the major centre of Chongqing and several smaller centres such as Fuling, Fengdu, and Wanxian. It is also joined in this reach by two partially navigable tributaries, the Jialing and the Wu. Just above Yichang, the river passes Gezhouba Dam.

Below Yichang, the river flows through a broad plain, passing through major agricultural regions to the industrial centre of Wuhan which lies some 630 km downstream. Several tributaries flow into the Yangtze between Yichang and Wuhan. The largest of these are the four rivers feeding Dongting Lake (Li, Yuan, Zi and Xian) and the Han which joins the main river at Wuhan.

Between Wuhan and Shanghai, the river maintains a wider and slower course. The Gan joins the main river at Poyang Lake, near the border of Hubei, Jiangxi and Anhui Provinces. Within this reach, the river passes through a well—developed agricultural and industrial region, before reaching the coastal port of Shanghai.

The Yangtze is an important link in the national transportation system. The Yangtze basin is densely populated and rich in natural resources. Forty percent of the nation’s foodstuffs are produced there on $25 \times 10^6$ hectares of farmland, and 40 percent of the nation’s industrial output is


Note: Navigable is defined as having a depth of 0.3 meters.
produced in the manufacturing centres. In addition, the region possesses substantial fishery, forestry and mineral resources.

An efficient transportation system is necessary to ensure that these products can move economically both within the Region and into other domestic and international markets. The Yangtze's role in providing an effective, low-cost inland water transport link within this overall transportation network is of major importance.

3.2 Physical Characteristics of the River

From the navigation perspective, the Yangtze can be divided into three reaches: a Lower Reach which extends from Shanghai to Wuhan; a Middle Reach between Wuhan and Yichang; and an Upper Reach which stretches from Yichang to Yibin but which, for purposes of mainline navigation, essentially terminates just above Chongqing. Each of these reaches involves different navigation conditions and limitations.

3.2.1 Lower Reach

The Lower Reach of the river, from Shanghai to Wuhan has generally excellent navigation conditions. Limiting channel depth is 8.0 – 9.0 metres below Nanjing and 4.0 – 4.5 metres above. Channel widths are generally in excess of 1,000 metres, and average annual velocity is in the range of 1.0 – 1.5 metres per second (m/s). Self-propelled vessels of up to 10,000 DWT can reach as far as Nanjing. Above Nanjing, tows with 5,000 t barges can be accommodated although a more typical configuration would consist of 12 – 15 barges at 1,000–1,500 t each.

3.2.2 Middle Reach

The Middle Reach of the river between Wuhan and Yichang is somewhat more limiting for navigation. For a 330 km stretch between Zhijiang, 60 km below Yichang, and Chenglingji, at the exit of Dongting Lake, the river channel is shallow and meandering with an average dry-season depth limitation of 2.9 metres and a limit of as little as 2.3 – 2.6 metres in extremely dry periods. In recent decades, the river channel through this reach has shifted many times, and frequent dredging and on-going bank reinforcement work is required in order to maintain satisfactory navigation conditions. In the section below Chenglingji, annual sediment deposition has created some problems with persistent shoaling which occasionally blocks navigation for short periods.

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2 Lin Bingnan, Li Guifen, op cit

3 These divisions between Reaches of the River may differ from those used in other documents. However, they are appropriate demarcations for describing navigation conditions.
Average annual velocities through the Middle Reach of the river are in the order of 1.5 m/s, somewhat higher than those below Wuhan. Limiting channel width is 80 meters, and bend radius is as low as 750 meters during low-flow periods. Typical tows in the Middle Reach consist of 6 to 9 barges of 1 000 – 1 500 t each, although larger tows can be handled for at least part of the year.

3.2.3 Upper Reach

The Upper Reach of the river, from Yichang to Chongqing, shown in detail in Plate 6.3 is the area which will be most directly affected by the construction of the Three Gorges Project. At the present time, navigation conditions through this reach are generally poor, and sometimes hazardous, both in dry and flood seasons.

There are 35 sections between Yichang and the Chongqing port facility at Jiulongpo which are limited to one-way operations during all or part of the year due to shallow depths, narrow channels, high velocities and tight bends. Table 3.1 describes these sections, showing their distance above Yichang and the channel characteristics during both dry and flood seasons. The Table also indicates the range of water surface elevations at which the one-way constraints apply.

In addition, there are 12 sections of the river where, either during high flow or low flow periods, channel velocities increase to the point where some or all of the cargo vessels require the assistance of winching stations (see Table 3.2). Eight of these 12 stations average more than 100 winching operations per year. The standard rule in determining winching requirements is that all tows may require winching at velocities over 4 m/s and low-powered vessels require winching when velocities exceed 2.5 m/s. Passenger vessels, however, can generally operate unassisted through high-velocity sections and do not normally require winching.

The winching and one-way sections are the main operating constraints in the Upper Reach of the river. However, general navigation conditions are also less attractive than in the Middle and Lower Reaches. In general, the minimum depth is 2.9 meters; however, at very low flows there are several sections where this depth cannot be maintained. Limiting channel width in the reach is 60 meters, and dry season velocities average 1.7 m/s while flood season velocities average in excess of 2.8 m/s.

Several sections of the river have a dry-season bend radius of less than 750 m. Two sections, at Huangcaxia and Tongluoxia Gorges, also have a flood-season bend radius of below 750 m. During the flood season, flows periodically exceed 45 000 m³/s, the level considered safe for navigation, and operations on the Upper River must be suspended.
### Table 3.1 - One Way Sections Yichang-Chongqing

<table>
<thead>
<tr>
<th>No.</th>
<th>Distance from Yichang (km)</th>
<th>Dry Season Width/Bend Radius/Max. Velocity (m, m, m/sec)</th>
<th>Flood Season Width/Bend Radius (m)</th>
<th>Chart Datum&quot;D&quot;(m)</th>
<th>One Way When Depth Is:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>154.0-155.8</td>
<td>98/750/2.02</td>
<td>270/750</td>
<td>61.0</td>
<td>All year</td>
</tr>
<tr>
<td>2</td>
<td>167.4-170.3</td>
<td>105/810/3.12</td>
<td>265/810</td>
<td>64.0</td>
<td>All year</td>
</tr>
<tr>
<td>3</td>
<td>179.0-180.7</td>
<td>102/2300/3.43</td>
<td>375/2300</td>
<td>67.0</td>
<td>&lt; D + 6 m</td>
</tr>
<tr>
<td>4</td>
<td>184.1-188.6</td>
<td>90/1110/3.20</td>
<td>336/1520/5.38</td>
<td>68.0</td>
<td>&lt; D + 13 m</td>
</tr>
<tr>
<td>5</td>
<td>194.0-195.0</td>
<td>120/680/2.50</td>
<td>492/960</td>
<td>71.5</td>
<td>&lt; D + 7 m</td>
</tr>
<tr>
<td>6</td>
<td>197.5-208.3</td>
<td>94/2070/2.00</td>
<td>240/1380</td>
<td>75.0</td>
<td>All year</td>
</tr>
<tr>
<td>7</td>
<td>215.8-217.0</td>
<td>111/1330/3.67</td>
<td>570/2190</td>
<td>76.5</td>
<td>&lt; D + 9 m</td>
</tr>
<tr>
<td>8</td>
<td>241.0-243.4</td>
<td>96/1510/4.27</td>
<td>460/2650</td>
<td>80.4</td>
<td>&lt; D + 6 m</td>
</tr>
<tr>
<td>9</td>
<td>247.7-250.0</td>
<td>60/2400/3.46</td>
<td>435/2600</td>
<td>83.0</td>
<td>&lt; D + 9 m</td>
</tr>
<tr>
<td>10</td>
<td>259.9-261.7</td>
<td>90/straight/4.65</td>
<td>480/straight</td>
<td>84.4</td>
<td>&lt; D + 8.5 m</td>
</tr>
<tr>
<td>11</td>
<td>267.4-270.6</td>
<td>150/2170/6.00</td>
<td>375/2550</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>282.5-294.8</td>
<td>65/2310/3.10</td>
<td>510/2500</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>286.3-287.4</td>
<td>105/2300/4.62</td>
<td>840/straight</td>
<td>88.0</td>
<td>&lt; D + 5 m</td>
</tr>
<tr>
<td>14</td>
<td>302.0-310.7</td>
<td>70/1430/2.90</td>
<td>610/2050</td>
<td>92.4</td>
<td>&lt; D + 3 m</td>
</tr>
<tr>
<td>15</td>
<td>345.0-349.8</td>
<td>70/1650/5.80</td>
<td>500/1750</td>
<td>101.1</td>
<td>All year</td>
</tr>
<tr>
<td>16</td>
<td>361.7-363.4</td>
<td>60/straight/3.12</td>
<td>530/straight</td>
<td>105.9</td>
<td>&lt; D + 5 m</td>
</tr>
<tr>
<td>17</td>
<td>366.4-369.1</td>
<td>70/1870/3.21</td>
<td>500/1870</td>
<td>107.0</td>
<td>&lt; D + 15 m</td>
</tr>
<tr>
<td>18</td>
<td>379.0-380.5</td>
<td>100/1850/3.00</td>
<td>860/2000</td>
<td>108.0</td>
<td>&lt; D + 5.5 m</td>
</tr>
<tr>
<td>19</td>
<td>393.0-395.2</td>
<td>75/1770/3.65</td>
<td>880/2300</td>
<td>110.5</td>
<td>&lt; D + 9 m</td>
</tr>
<tr>
<td>20</td>
<td>398.3-400.0</td>
<td>80/1820/3.20</td>
<td>820/straight</td>
<td>113.0</td>
<td>&lt; D + 9 m</td>
</tr>
<tr>
<td>21</td>
<td>403.3-412.3</td>
<td>110/940/3.15</td>
<td>490/1860</td>
<td>115.0</td>
<td>D+1-12 m</td>
</tr>
<tr>
<td>22</td>
<td>449.4-459.9</td>
<td>110/1690/3.60</td>
<td>810/straight</td>
<td>125.0</td>
<td>&lt; D + 2 m</td>
</tr>
<tr>
<td>23</td>
<td>483.0-486.0</td>
<td>70/straight/2.50</td>
<td>920/straight</td>
<td>131.5</td>
<td>&lt; D + 5.5 m</td>
</tr>
<tr>
<td>24</td>
<td>494.2-495.3</td>
<td>72/990/2.70</td>
<td>460/1680</td>
<td>132.5</td>
<td>D+5 - 13 m</td>
</tr>
<tr>
<td>25</td>
<td>505.0-508.6</td>
<td>100/1340/3.20</td>
<td>1000/1640</td>
<td>133.0</td>
<td>&lt; D + 8 m</td>
</tr>
<tr>
<td>26</td>
<td>518.5-519.4</td>
<td>230/1370/3.20</td>
<td>1128/1370</td>
<td>136.5</td>
<td>D+5 - 15 m</td>
</tr>
<tr>
<td>27</td>
<td>558.7-559.7</td>
<td>60/825/3.60</td>
<td>728/1200</td>
<td>140.5</td>
<td>&lt; D + 2.5 m</td>
</tr>
<tr>
<td>28</td>
<td>564.0-566.9</td>
<td>120/520/3.53</td>
<td>975/1220</td>
<td>142.5</td>
<td>&lt; D + 1.5 m</td>
</tr>
<tr>
<td>29</td>
<td>573.9-574.5</td>
<td>120/700/2.90</td>
<td>340/700/4.86</td>
<td>144.0</td>
<td>&lt; D + 9 m</td>
</tr>
<tr>
<td>30</td>
<td>582.2-587.7</td>
<td>70/810/3.21</td>
<td>660/1680</td>
<td>146.0</td>
<td>&lt; D + 9 m</td>
</tr>
<tr>
<td>31</td>
<td>593.5-594.5</td>
<td>60/1005/3.0</td>
<td>540/2100</td>
<td>148.5</td>
<td>&lt; D + 1.5 m</td>
</tr>
<tr>
<td>32</td>
<td>604.0-606.2</td>
<td>60/520/3.2</td>
<td>650/1700</td>
<td>151.0</td>
<td>&lt; D + 3.5 m</td>
</tr>
<tr>
<td>33</td>
<td>639.5-641.5</td>
<td>75/1140/2.95</td>
<td>840/1620</td>
<td>156.0</td>
<td>&lt; D + 2 m</td>
</tr>
<tr>
<td>34</td>
<td>644.0-645.2</td>
<td>150/720/2.90</td>
<td>258/720/7.0</td>
<td>158.2</td>
<td>All year</td>
</tr>
<tr>
<td>35</td>
<td>669.7-674.3</td>
<td>96/600/3.65</td>
<td>1451/1000</td>
<td>164.0</td>
<td>&lt; D + 3 m</td>
</tr>
</tbody>
</table>
### Table 3.2 - Winching Stations Above Yichang

<table>
<thead>
<tr>
<th>No.</th>
<th>Distance from Yichang (km)</th>
<th>Winching Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>176.8</td>
<td>Nov.-May</td>
</tr>
<tr>
<td>2*</td>
<td>191.6</td>
<td>Mid Nov.-May</td>
</tr>
<tr>
<td>3*</td>
<td>196.7</td>
<td>Dec.-May</td>
</tr>
<tr>
<td>4*</td>
<td>226.6</td>
<td>May-Nov.</td>
</tr>
<tr>
<td>5</td>
<td>231.6</td>
<td>Mar.-May, Nov.-Dec.</td>
</tr>
<tr>
<td>6</td>
<td>235.5</td>
<td>June-Oct.</td>
</tr>
<tr>
<td>7*</td>
<td>243.4</td>
<td>Nov.-May</td>
</tr>
<tr>
<td>8*</td>
<td>252.7</td>
<td>Jan.-Apr.</td>
</tr>
<tr>
<td>9*</td>
<td>255.5</td>
<td>Oct.-June</td>
</tr>
<tr>
<td>10*</td>
<td>261.6</td>
<td>Mid Nov.-May</td>
</tr>
<tr>
<td>11*</td>
<td>347.2</td>
<td>May-Nov.</td>
</tr>
<tr>
<td>12</td>
<td>488.9</td>
<td>June-Sept.</td>
</tr>
</tbody>
</table>

* more than 100 operations per year
The above constraints severely limit navigation in the Upper Yangtze. The maximum tow size in the Upper Reach is between 3 and 4 × 10⁶ t barges. Furthermore, when operating upbound, tows are capable of only about a 40% load factor since the required power to weight ratio increases significantly in the upbound direction. In addition, high velocities and numerous controlled sections result in longer travel times through this part of the river.

3.3 Present Operations on the River

3.3.1 Traffic and Operators — Yangtze System

In 1984, freight traffic on the entire Yangtze River System, including tributaries, was in the order of 220 × 10⁶ t, representing 71 × 10⁹ tonne kilometers (tkm). Just under half of the tonnage, 104 × 10⁶ t, and over two thirds of the tonne kilometers, 52 × 10⁹ tkm, moved on the main stem of the river.

The largest operator on the Yangtze is the Changjiang Shipping Company (CSC) which is under the direct responsibility of the Ministry of Communications (MOC). CSC provides freight and passenger service on the main stem of the river. In 1984, it carried approximately half of the total tonnage on the main river but accounted for over 60% of the tkm. In addition, CSC carried over 30 × 10⁶ passengers in 1984, representing a total of 6 × 10⁹ passenger-kilometers (pkm).

The remaining freight traffic on the river is carried by privately owned companies, provincial shipping companies and small local operators. The largest private company, the Mingsheng Shipping Company of Chongqing, provides freight service from Chongqing to Shanghai. The provincial shipping companies have traditionally focussed on freight movements within their province. However, with the easing of operating restrictions in recent years, some provincial companies are now carrying freight over longer distances and providing inter-provincial service. Local operators generally operate within a limited area, using small tugs and barges to provide service between nearby communities.

Most of the inter-city passenger services are operated by CSC. Some passenger service is provided by local operators, generally over short distances between nearby communities or simply from one side of the river to the other. In recent years there has also been a substantial growth in tourist passenger services on the river. Tourist vessels, however, offer a more leisurely sight-seeing, cruise-type operation as opposed to an inter-city passenger service.

3.3.2 Traffic and Operators — Upper Reach

In the Upper Reach of the Yangtze above Yichang, the main operating companies are CSC (providing freight and passenger service between the main ports), Mingsheng Shipping Company, the Provincial Shipping
Companies of Sichuan, Yunnan, Guizhou and Hubei Provinces, and a number of small local operators. CSC's share of through freight traffic has declined somewhat in recent years. In 1982, CSC carried about two thirds of the freight tonnage moving in and out of Sichuan. By 1985, this had declined to approximately one-half.

Coal, phosphorus, petroleum products, steel, and timber appear to be the main commodities moved on the Upper Yangtze although a substantial volume of cargo is categorized as "other".

No detailed statistics are available on the total water-borne freight movements in the Upper Yangtze. While statistics have been collected for movements through the Gezhouba Locks above Yichang, and some data is available regarding the downstream traffic of the Chongqing Branch of CSC, it is difficult to reconcile the data from different sources or to obtain a complete and accurate picture of total traffic in the Upper Reach. As a result, it has been necessary to assume that traffic through Gezhouba Locks represents a reasonable measure of activity in the Upper Reach of the river.

In 1985, the total traffic through Gezhouba Locks was $5.5 \times 10^6$ t: $4.4 \times 10^6$ downbound and $1.1 \times 10^6$ upbound. The commodity breakdown is shown in Table 3.3 below.

### THREE GORGES PROJECT FEASIBILITY REPORT

#### TABLE 3.3 — 1985 TRAFFIC THROUGH GEZHOUBA SHIPLOCKS

<table>
<thead>
<tr>
<th>(t x 10^3)</th>
<th>Upbound</th>
<th>Downbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Products</td>
<td>291.7</td>
<td>—</td>
</tr>
<tr>
<td>Timber</td>
<td>—</td>
<td>194.7</td>
</tr>
<tr>
<td>Phosphate rock</td>
<td>—</td>
<td>417.5</td>
</tr>
<tr>
<td>Coal</td>
<td>—</td>
<td>2792.1</td>
</tr>
<tr>
<td>Aggregate/sand</td>
<td>—</td>
<td>421.6</td>
</tr>
<tr>
<td>Fertilizers</td>
<td>145.6</td>
<td>—</td>
</tr>
<tr>
<td>Steel</td>
<td>273.6</td>
<td>—</td>
</tr>
<tr>
<td>Cement</td>
<td>52.1</td>
<td>—</td>
</tr>
<tr>
<td>Other</td>
<td>346.4</td>
<td>609.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1108.4</td>
<td>4435.5</td>
</tr>
</tbody>
</table>

**Source:** Gezhouba Shiplocks Corporation

By comparison, total traffic through Gezhouba in 1982 was $3.5 \times 10^6$ t of which $2.6 \times 10^6$ moved downbound and $0.9 \times 10^6$ moved upbound. The major factor underlying the growth between 1982 and 1985 was an increase in coal movements. Downbound coal traffic grew from $0.45 \times 10^6$ t in 1982 to $2.79 \times 10^6$ t in 1985. In fact, if coal is excluded from the total, downbound traffic declined over the period by $0.5 \times 10^6$ t.
Approximately \( 2.2 \times 10^6 \) passengers moved through Gezhouba in 1985, \( 1.2 \times 10^6 \) downbound and \( 0.9 \times 10^6 \) upbound. This was also a significant increase over 1982 when a total of \( 1.3 \times 10^6 \) passengers moved through the locks.

A more detailed description of current and past traffic is provided in Appendices A and B which discuss traffic forecasts through the Upper Yangtze Corridor.

### 3.3.3 Operating and Cost Parameters

Equipment used for freight and passenger movements in the Upper Reach varies according to the operator. The main vessel types are shown in Table 3.4.

The current costs of vessel operations on the Yangtze are indicated in part by the formulae used to calculate tariffs. According to the Provincial shipping companies, basic tariffs are as follows:

**Provincial Companies:**

\[
\text{Yuan/t} = 2.2 + 0.01 (2.8 \text{ LU} + 1.7 \text{ LM} + 1.5 \text{ LL})
\]

**CSC:**

\[
\text{Yuan/t} = 1.5 + 0.01 (2.8 \text{ LU} + 1.3 \text{ LM} + 0.735 \text{ LL})
\]

where:
- \( \text{ LU} \) is the distance traversed in the Upper Reach
- \( \text{ LM} \) is the distance traversed in the Middle Reach
- \( \text{ LL} \) is the distance traversed in the Lower Reach

The tariff formula implies a marginal operating cost of 2.8 fen per tkm in the Upper Reach of the river. Tariffs are set, however, to cover the financial costs of operations. As such, they reflect costs based on administered prices for many inputs, existing load factors, and book value rather than replacement costs of equipment.

In order to obtain an indication of long-run economic costs of operations, it was necessary to develop independent estimates of shipping costs. These estimates were based on operating data and unit cost information provided by CSC, Mingsheng Shipping Company, and Hubei Provincial Shipping Company. Shadow prices were used for key inputs where there were major distortions in the financial prices, most notably in fuel and equipment costs. In addition, annual capital cost was calculated on a fully allocated marginal cost basis using prices, either actual or estimated, for new equipment and including a 10% cost of capital in the annual cost figure.
THREE GORGES PROJECT FEASIBILITY REPORT

TABLE 3.4
TYPICAL VESSEL CHARACTERISTICS – UPPER YANGTZE

<table>
<thead>
<tr>
<th>Type</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSC Tow</td>
<td>2 640 hp tug&lt;br&gt;3 x 1 000 tonne barges&lt;br&gt;tug – 46m x 10.8m x 2.4m&lt;br&gt;barges – 75m x 10.8m x 2.4m each</td>
</tr>
<tr>
<td>Mingsheng Tow</td>
<td>800 – 1 200 hp tug&lt;br&gt;3 x 800 tonne barges&lt;br&gt;barges – 64m x 11m x 2.2m each</td>
</tr>
<tr>
<td>Provincial Tow</td>
<td>400 hp tug&lt;br&gt;3 x 500 tonne barges&lt;br&gt;barges – 45m x 10.8m x 1.8m each</td>
</tr>
<tr>
<td>Local Tow</td>
<td>240 hp tug&lt;br&gt;4 x 80 tonne barges</td>
</tr>
<tr>
<td>CSC Passenger Vessel – Large</td>
<td>2 640 hp&lt;br&gt;84.5m x 17m x 2.4m&lt;br&gt;1 100 passengers</td>
</tr>
<tr>
<td></td>
<td>2 640 hp&lt;br&gt;74m x 13.6m x 2.4m&lt;br&gt;863 passengers</td>
</tr>
</tbody>
</table>

Source: Discussions with MOC and vessel operators
A vessel costing model was developed to calculate the total costs for different tow and vessel configurations over a number of routes. The structure and detailed assumptions of this model are outlined in Appendix D of this report.

Based on current operating parameters as defined by the various operators, it is estimated that the fully-allocated cost of freight transport in the Upper Reach of the Yangtze (for a movement from Chongqing to Yichang) ranges from 4.9 fen per tkm for CSC to 6.1 fen for Provincial operators and 15.0 fen per tkm for small local tows. Passenger vessel costs are estimated at 11.9 fen per passenger-kilometre for the large and medium ferries.

For movements from Chongqing to Wuhan, average costs per tkm decline, partly due to the fact that fixed port costs are spread over a larger number of tkms but also due to the improved operating conditions in the Middle Reach. CSC costs for the Chongqing—Wuhan movements are estimated at 3.7 fen per tkm.

By comparison, the current CSC tariff for Chongqing to Yichang is approximately 3.0 fen per tkm. For a trip from Chongqing to Wuhan, the average tariff would be in the order of 2.2 fen per tkm.

The spread between water-borne costs and tariffs, while significant, is less than the cost—tariff spread for rail movement over the same route. The estimated long—run marginal cost of rail movement from Chongqing to Wuhan is 3.8 fen per tkm, while typical railway tariffs for bulk commodities are in the order of 1.3 to 1.7 fen.

3.4 Channel Maintenance and Operations

Maintenance and operation of the river channel is the responsibility of the Yangtze Valley Navigation Administration (YVNA), a branch of the Ministry of Communications. Information on existing channel maintenance activity was obtained through discussions with YVNA and from previous YVPO Reports. While the information is not comprehensive, it provides an indication of current activities and costs.

3.4.1 Dredging

YVPO's 1985 Preliminary Design Report indicated that annual dredging in the upper channel averaged 240 x 10^3 m^3 at an estimated cost of 2.64 x 10^6 yuan or 11 yuan per m^3. In addition, it indicated that dredging in the Middle Reach averaged 3 x 10^6 m^3 per year at an estimated cost of 3.6 x 10^6 yuan, or 1.2 yuan per m^3. The latter is primarily local dredging, however, and dredge material can be easily disposed of by depositing it behind the adjacent dikes.
Discussions with YVNA confirmed that some annual dredging is carried out in the Chongqing–Yichang section of the river. Both trailing suction and suction cutter dredges are used, with diameters in the 500 mm to 700 mm range. YVNA stated that average costs for dredging gravel are approximately 20 yuan per m³, while costs for dredging and disposing of sand and silt are closer to 5 yuan per m³. These costs are higher than those given in the YVPO report. However, they represent more recent experience and are reasonable when compared to typical dredging costs elsewhere.

3.4.2 Navigation Aids

Between Shanghai and Chongqing, the river channel is equipped with lighted navigation aids. Above Chongqing the aids are not lighted. Most of the aids in the Upper Reach are floating although there are some shore—based aids as well. The floating aids require almost continuous maintenance and adjustment as the river stage rises and falls.

3.4.3 Winching

As noted in Section 3.2, there are 12 winching stations between Yichang and Chongqing which assist tows through high—velocity sections. Some stations operate during low—flow periods, while others are required when the river reaches intermediate or flood stages.

Winching stations consist of a winch barge which is anchored to the shore, and a tug which carries the winch cable to the tow requiring assistance. A tow approaching the station is supposed to signal ahead if it will require winching at which time the winch tug can be dispatched to meet it. Typical winching distances do not exceed 600 meters, and an operation is reported to require some 15 minutes. However, it is understood that in some cases the tow does not request winching until it has found that it cannot proceed upstream unassisted. In such cases the winching period is substantially longer. No downstream passage is allowed while a tow is being winched.

In 1983 there were a total of 1 366 winching operations in the Upper Reach (YVPO, 1985). These were divided among 13 winch stations. However, since many of these winching operations may involve a single vessel which requires assistance through several stations, it is not possible to compare this with total vessel movements or total tonnage moving on the river. No costs were provided for 1983, but in 1982 the cost of winning operations was 576 x 10³ yuan.

3.4.4 Traffic Control

There is no overall traffic control on the Upper Reach of the river. However, local control is exercised at one—way sections and at the Gezhouba locks.
The 35 one-way sections in the reach between Yichang and Chongqing are controlled by local signal stations above and below the restriction. These stations have both radio and "semaphore" signals to control traffic and indicate the direction that traffic may proceed. Signal stations are manned by three or four people, usually working on rotating one-man shifts.

At Gezhouba there is a radio-equipped traffic control station. The control centre determines the allocation of lockage space and the scheduling of vessels through the locks.

3.4.5 Annual Maintenance Costs

According to YVNA, annual expenditures on channel maintenance and operations in the reach above Gezhouba average 10 x 10^6 yuan. It is understood that this covers dredging, winching, surveying and operation of one-way control sections.

3.5 Capacity of the River Channel

3.5.1 Measurement of Capacity

The annual amount of traffic which can be passed through a river channel, or through navigation structures such as locks and shiplifts, depends on a number of factors including:

- the number of vessels which can be handled past a point on an hourly basis,
- the annual operating hours;
- the smoothness or lack of smoothness in demand on both an annual and a daily basis; that is, the extent to which total vessel arrivals are spread evenly throughout the time period;
- the mix between cargo and non-cargo or passenger vessels; and
- the average amount of freight carried on each cargo vessel.

All of these factors can vary over time, as a result of changes in vessel design, changes in fleet mix, changes in traffic control procedures, or changes in the mix of traffic demand on the river. At some point, these operational factors will reach optimal levels, and beyond that point the physical characteristics of the river will define the upper limit of potential capacity which can only be surpassed by altering the width, depth or velocity of the river channel. However, it is possible to put forward several defensible estimates of the capacity of a particular river channel, each based on the same set of physical constraints but each using a different set of assumptions regarding traffic and operating procedures.
It is therefore important, when specifying capacities of different navigation channels or facilities, to ensure that the underlying assumptions are consistent, and that differences in capacity reflect differences in physical characteristics. In assessing the capacity both of the Upper Reach of the Yangtze and of the proposed navigation facilities at Three Gorges, care has been taken to ensure that underlying operational assumptions are consistent and clearly defined. However in many cases, either as a result of expected changes in operating procedures or as a result of uncertainties about traffic levels, it was necessary to examine capacity under a number of assumptions regarding operating factors.

As a consequence, the sections of this volume which deal with current and future capacity of the river system generally present a range of capacity figures which, while tied to one set of physical conditions, reflect a number of alternatives relating to traffic levels and evolution of the fleet.

### 3.5.2 Capacity of the Existing Upper Channel

The general formula for calculating the annual capacity (C) of the river channel is shown below. This formula was adapted from work carried out by YVPO and MOC relating to capacity of the proposed navigation facilities.

\[
C = \frac{\text{Ave.t/transit} \times \text{Transits/hr} \times \text{Hrs/day} \times \text{Days/Year}}{\text{Adjustment for random arrivals}}
\]

The primary focus in assessing the existing capacity of the Upper Reach of the Yangtze was on defining the nature and severity of the constraints imposed by the physical conditions in the channel, and the impact of these constraints on the values which would be used in the capacity formula. Potentially limiting conditions in the Upper Yangtze include high flows during the flood season, poor visibility due to fog, winching stations which operate during different seasons, and one-way sections which are in effect for either all or part of the year. Each of these can affect the number of operating hours per year, the number of vessels which can be passed in each hour, and the maximum and average vessel size.

The detailed methodology and findings of the channel capacity studies are provided in Appendix C of this Report. The main steps involved were:

- review of information supplied by YVPO relating to operating conditions and capacity in the Upper Reach of the river;
- review of MOC standards for one-way and two-way operations on the river, as well as standards established by the U.S. Army Corps of Engineers, in order to define the relationship between tow-sizes, bend radius, channel dimensions and operating conditions;
- review of the data provided by YVPO on conditions at the various winching stations and one-way sections;
examine the navigation charts for critical areas of the river; and

- analysis of output from the HEC–2 Water Surface Profiles model of the river, which provided the channel widths, depth and velocity at 175 gauge points in the Upper Reach under a range of flow conditions.

Based on this review, a number of preliminary conclusions were drawn regarding the capacity of the Upper Reach of the River. The findings of this initial review were then discussed in detail with senior engineering staff from the Yangtze Navigation Administration in Beijing. As a result of these discussions, further adjustments were made and a range of capacity estimates were developed for different tow sizes and fleet compositions.

Table 3.5 below summarizes the estimated downstream channel capacity under a range of average tow sizes. Upstream capacity would be about 40% of these figures due to the limits on upstream loads under existing horsepower/weight ratios. The tow sizes are representative of the current and anticipated future cargo-carrying fleet on the river. Three figures are shown for capacity — the first with no allowance for passenger vessel transits, the second with an allowance for 6 passenger vessels per day, and the third with an allowance for 12 passenger vessels per day.

THREE GORGES PROJECT FEASIBILITY REPORT

TABLE 3.5 — ESTIMATED DOWNSTREAM CAPACITY OF THE UPPER REACH

(10⁶ t per annum)

<table>
<thead>
<tr>
<th>Average Tow Size</th>
<th>Passenger Vessels per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>1 000 t¹</td>
<td>9.3</td>
</tr>
<tr>
<td>2 000 t</td>
<td>18.5</td>
</tr>
<tr>
<td>2 400 t²</td>
<td>22.2</td>
</tr>
<tr>
<td>3 000 t³</td>
<td>27.7</td>
</tr>
</tbody>
</table>

¹ approximates existing tow mix

² equivalent to 75% of traffic in 3 x 1 000 t tows and 25% in 3 x 500 t tows — within the ability of the existing channel

³ would require that all traffic be carried in maximum—size (3 x 1 000 t) tows
Table 3.5 clearly shows the impact of both average tow size and number of passenger vessel movements on the freight capacity of the channel. Under existing channel conditions, a shift from zero to 12 daily passenger vessels reduces the effective freight-carrying capacity of the channel by more than 35%.

While the above capacities represent a best estimate given the existing physical characteristics of the river, it should be noted that there are factors other than the physical conditions which could influence the calculations. For example, utilization of more powerful tugboats, a change in barge design to permit larger loads within the same overall dimensions, the implementation of better traffic control procedures through one-way and winching sections, or provision of additional aids to permit extended navigation hours could all serve to increase channel capacities beyond those estimated above. However, the assumptions used are considered to be a reasonable representation of the capacity of the existing channel under present conditions.
4. FUTURE NAVIGATION ON THE UPPER YANGTZE WITHOUT THREE GORGES PROJECT

In order to assess the impact of Three Gorges Project on the navigation sector, it is necessary to consider the future characteristics of navigation on the Upper Yangtze in the event that the Project is not built. This provides a reference point both for defining the changes which are attributable to the Project and for measuring the Project's economic benefits. The following sections discuss the way in which navigation might evolve without Three Gorges in terms of the physical characteristics of the river, volume of traffic, vessel operating parameters and costs.

4.1 Physical Characteristics of the River

If Three Gorges Project is not built, it is unlikely that there will be any significant physical change in the Upper Yangtze channel. Navigation will continue to be constrained by one-way control sections, particularly in areas where sharp bends are combined with narrow channels and high velocities; low-powered tows will continue to require assistance over the rapids which occur seasonally; and river currents will reduce the carrying capacity of upbound tows.

Some of these problems could be alleviated by capital works projects. For example, MOC has identified a scheme of channel improvements which they anticipate would increase the capacity of the Upper Channel to 30 x 10^6 t per year at an estimated capital cost of 1.16 x 10^9 yuan. While details of this proposal have not been provided, it is understood that the main components involve deepening some critical sections of the channel and widening the approaches to one-way sections. This would permit the use of somewhat larger tows (MOC has estimated a weighted average of 3 800 t per tow with a maximum tow of 4 100 t in calculating the 30 x 10^6 t of capacity), and could allow more daily transits through constraining sections.

Such a program would not, however, have any impact on the average velocities in the river; nor would it eliminate the need for many of the one-way control sections. As such, it will not have a major effect on vessel speeds, fuel consumption or operating costs. Without some reduction in vessel operating costs, water transport will have difficulty competing with overland modes for additional traffic and there is therefore some doubt as to whether such channel improvements would be economic.

Consequently, it is expected that the physical characteristics of the Upper Reach will remain substantially unchanged in the event that Three Gorges Project is not built.
4.2 River Operations

4.2.1 Expected Freight and Passenger Traffic

The amount of traffic expected to move through the Upper Reach of the Yangtze in future years has been the subject of some debate among the various parties which have been concerned in the planning of Three Gorges. For example, forecasts of downbound water-borne freight demand in the year 2000 range from $10 - 12 \times 10^6$ t (YVPO), to $20 \times 10^6$ t (MOC) and $25 \times 10^6$ t (Port of Chongqing). Upbound freight is expected to be about 25% of the downbound volumes.

For the year 2030, all three groups estimate that the downbound water-borne traffic demand will reach $50 \times 10^6$ t, while upbound traffic will reach approximately $12.5 \times 10^6$ t.

The forecasts developed by YVPO, MOC and the Port of Chongqing were based on a combination of trend projections, discussions with provincial and regional authorities, and a general assessment of factors which might lead to traffic growth. The basic differences over the period between 1987 and 2000 related to a difference of opinion regarding the extent and timing of mineral resource developments (primarily coal and phosphate rock) in Sichuan, Guizhou and Yunnan.

CYJV has discussed the forecasts and the forecasting methodologies with each of the groups. These discussions prompted concerns that the forecasts might be overly optimistic or at least somewhat biased by the heavy weighting given to recent trends and to the opinions of local groups. In addition, since there were few firm commitments to develop the upstream mineral resources, there were concerns regarding the extent to which investment funds would be forthcoming in the next decade and hence the extent to which these mineral resources will contribute to future traffic.

CYJV therefore developed an independent forecast for future freight traffic. This forecast attempted to review the development and transport of goods and resources in the Upper Yangtze region within the context of national and regional supplies and requirements for these products. In addition, traffic was assessed for the total Upper Yangtze corridor, including those commodities which were, or might be expected to move by rail.

Development of the forecasts was hampered by a lack of data on the volumes, origins and destinations of existing traffic and by a lack of information on the potential for future trade, either in resources or finished products, between Southwest China and other provinces. The forecasts therefore involved varying depths of analysis. Products currently moving by rail and water were evaluated on a commodity-by-commodity basis. Future resource and industry development in regions adjacent to the river was assessed based on information collected in the resettlement
studies, and future new resource and industry development in Southwest China was assessed on a largely subjective basis, using the limited data available regarding national development plans.

Due to the uncertainties, two forecasts were developed, one based on fairly conservative assumptions regarding traffic growth and the other based on a more optimistic set of assumptions. The detailed methodologies and assumptions of this forecasting exercise are provided in Appendix A.

The CYJV forecasts for total freight traffic through the Upper Yangtze Corridor and the water-borne share of these totals are shown in Table 4.1 below.

**THREE GORGES PROJECT FEASIBILITY REPORT**

**TABLE 4.1 — CYJV FORECAST TOTAL AND WATER-BORNE FREIGHT TRAFFIC WITHOUT THREE GORGES PROJECT**

<table>
<thead>
<tr>
<th></th>
<th>Total (t x 10^6)</th>
<th>Water (t x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Down</td>
<td>Up</td>
</tr>
<tr>
<td>Actual Average 1982 – 1985</td>
<td>7.4</td>
<td>3.6</td>
</tr>
<tr>
<td>2000 – Low</td>
<td>11.0</td>
<td>6.4</td>
</tr>
<tr>
<td>– High</td>
<td>14.9</td>
<td>6.8</td>
</tr>
<tr>
<td>2030 – Low</td>
<td>24.7</td>
<td>11.5</td>
</tr>
<tr>
<td>– High</td>
<td>38.3</td>
<td>17.4</td>
</tr>
</tbody>
</table>

The water share is based on the assumption that there will be no significant change in vessel operating costs over the time frame, a subject which is discussed further in the next section. Water transport is projected to capture all of the growth in commodity traffic now moving by water, plus any new traffic which develops within the reservoir region, plus 10% of traffic associated with growth in inter-regional trade. Water traffic does not, however, include any share of projected growth in existing rail freight movements.

CYJV also developed estimates of future river passenger traffic. Since no data was available on the structure of the market for passenger travel on the river, it was not possible to develop forecasts by market segment (e.g. local tourist, foreign tourist, business, family visits, etc.) The passenger forecasts were therefore based on general relationships between income
growth, total travel demand and waterborne passenger travel. These were then linked to forecast growth in personal income within China. Details of these forecasts are provided in Appendix B.

The resultant estimates of passenger travel through the region ranged from 4.1 to $5.2 \times 10^6$ person-trips in the year 2000 of which between 2.3 and $3.0 \times 10^6$ would be downbound. This implies between 9 and 12 daily downbound transits of passenger vessels, as opposed to the existing 6 daily transits through Gezhouba, if average passengers per vessel remain relatively constant.

By 2030, passenger volumes are estimated at between 9.0 and $11.6 \times 10^6$ person-trips. Of these, between 5.1 and $6.6 \times 10^6$ would be downbound. This would result in 20 to 26 one-way passenger vessel movements per day at current vessel loadings. However, as noted in Appendix B, with the anticipated growth in passenger demand the average number of passengers per vessel would likely increase and daily vessel movements would not reach these levels. On the other hand, if a substantial portion of the growth in passenger movements is tourist related, there could be a greater increase in passenger vessel movements due to the low number of passengers carried on each cruise ship.

### 4.2.2 Vessel Operating Characteristics and Costs

It is expected that even in the absence of Three Gorges Project there will be some changes in the characteristics of vessel operations on the Upper Yangtze, both in response to changing traffic demand and as a natural evolution towards greater operating efficiency. While the physical characteristics of the river will continue to impose limits on tow sizes and operating speeds, there are other operating improvements which could be implemented without major capital investment and which would yield time and cost savings to river operators.

Opportunities for improvements in the absence of Three Gorges would include reductions in port time and crew costs, particularly for CSC tows which are primarily serving large centres. In addition, some extension of daily operating hours would be possible with better communications and traffic control procedures. Increased radio communication between tows, for example, would permit additional night-time movement and could facilitate passage through one-way sections. Limitations on the use of under-powered vessels would also serve to improve operating conditions for larger vessels and increase river capacity.

Due to the lack of any significant change in the physical characteristics of the river, it is not expected that there will be a major change in the type of equipment used by either freight or passenger operators. With higher traffic volumes, there may be some increase in the average size of tow, but for this analysis maximum tow sizes were assumed to be limited to those pertaining at the present time.
The above assumptions represent a fairly conservative view of the operating improvements which might be made in the absence of Three Gorges, focussing as they do on low-cost, readily implemented measures.

There are a number of more capital-intensive actions which might prove cost-effective, including redesigning barges to increase cargo capacity within existing overall dimensions, using higher-powered tugs to increase the capacity of upbound tows, or installing bow-thrusters on large tows to facilitate manoeuvring through bends in the river. To determine whether such investments are warranted in terms of resultant savings and anticipated traffic demand would require a detailed analysis of technical and economic viability. In view of the relatively low traffic levels projected by CYJV, it is questionable whether they are justifiable and therefore whether investment funds would be forthcoming.

The details of the assumptions regarding vessel operating parameters if Three Gorges Project is not built are outlined in Appendix D on Vessel Costing. Using the vessel costing model together with these revised parameters, it was estimated that in the intermediate to long term the cost per tkm for a CSC 3 x 1 000 t tow would decline as follows:

Existing and Future Barge Costs
(Without Three Gorges Project)
(Fen per Tkm)

<table>
<thead>
<tr>
<th></th>
<th>1986</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chongqing–Yichang</td>
<td>4.9</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Chongqing–Wuhan</td>
<td>3.7</td>
<td>3.0</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Provincial and local tows would also benefit from longer operating hours and potential reductions in port time and delays, achieving savings proportionate to those of the CSC tow. Passenger vessels, however, which currently spend little time in port and operate during night hours would benefit to a lesser extent.

4.3 Capacity of the River Channel

As noted in Section 4.1 above, it is not expected that there will be any significant change in the physical characteristics of the Upper Reach of the river if Three Gorges Project is not built. The existing constraints to navigation, including winching stations, one-way sections, and high velocities, will continue to impose limits on the capacity of the river. It is anticipated, however, that as a result of higher traffic demand and potential improvements in traffic control procedures, there will be some
shift towards longer operating hours. In addition, the higher demand may lead to higher proportion of large tows in the overall traffic mix.

If these improvements are achieved, the annual one-way capacity of the Upper Yangtze would approach the maximum levels defined in Table 3.5 (Section 3.5.2); that is:

- $13.9 \times 22.2 \times 10^6$ t with an average of 2 400 t per tow, or
- $17.3 \times 27.7 \times 10^6$ t with an average of 3 000 t per tow.

If the Three Gorges Project is built, the physical and operating environment of the navigation sector will change markedly. The first phase of change will occur during the construction period, when construction activity at the damsite will create a new set of operating conditions around Sandouping. These conditions will pertain until the middle of year 12 when filling of the reservoir is scheduled to begin and the permanent navigation structures will come into service. Assuming a starting date early in 1989, this phase of the construction period will extend until mid-2000.

5.1 Physical Characteristics of the River

5.1.1 YVPO Proposed Facilities at the Project Site

The facilities which have been proposed in the YVPO 1985 Preliminary Design Report to provide navigation past the damsite during the construction period include:

- a diversion channel
- a temporary navigation lock, 240 m x 24 m
- a shiplift, 120 m x 18 m

Plate 6.4 shows the general location of these facilities within the overall project layout.

The diversion channel would be located on the right side of the river. It would be 350 m wide and approximately 3.5 km long. The temporary lock would be located at the left bank of the river and would have a maximum operating water level of 76.7 metres. When filling of the reservoir begins, the temporary lock would be blocked off with stop logs and would no longer be available for service.

The shiplift would also be located on the left bank of the river. It is designed to operate over the full range of water levels that will be experienced both during the construction period and once the reservoir is in operation. As such, it would serve as both a temporary and a permanent facility. However, with the exception of a 4 to 6 week reservoir filling period, it would always operate in conjunction with other navigation facilities.

The procedures proposed for handling navigation around the construction site change as construction progresses. The various construction Phases are described in detail in Volume 2 and are only briefly reiterated in this section. Figure 5.1 illustrates the availability of the temporary navigation
* Based on the construction schedule for the Recommended Project
facilities in relation to the expected construction dates. The construction
dates cited are those associated with a 18 year construction schedule, with
initial reservoir impoundment midway through year 12.

During the Preparatory Phase and Phase I of construction (i.e. Year 1 to
December of Year 6, which includes construction of the Stage I cofferdam
and the diversion channel) navigation would continue to use the main river
channel.

During Phase II, (December of Year 6 to December of Year 11) when the
main river is cofferdamed for construction of the main spillway and the
left–bank powerhouse, navigation would be diverted from the main channel
and accommodated by a combination of the diversion channel, the
temporary lock and the shiplift. Beginning in December of Year 6,
navigation would be routed to the diversion channel. By May of Year 7,
the temporary lock is to be completed, allowing navigation to be routed
through the lock and the channel as traffic and flow conditions dictate.
In May of Year 10, the shiplift is to be completed and all three facilities
would be available for navigation.

At the beginning of Phase III, (December of Year 11), the diversion
channel is closed off as construction begins on the right bank cofferdam
and powerhouse facilities. Navigation would then be handled through the
temporary lock and shiplift until May of Year 12 when filling of the
reservoir begins. When the reservoir level reaches about El 76, the
temporary lock would be closed off, and navigation would then be
restricted to the shiplift until the reservoir reaches 130 m and the
permanent locks come into service.

It is expected that the reservoir can be raised to El 130 in about four
weeks. As soon as that reservoir level is reached, navigation would be
routed through the permanent locks as well as the shiplift. This would be
the permanent navigation arrangement, and no further changes would be
required when the reservoir is later raised to the normal operating range.

5.1.2 Operation of the Proposed Temporary Navigation Facilities

During Phase II and early Phase III of the project’s construction, when
navigation would be confined to the temporary facilities, the use and
operation of the diversion channel, lock and shiplift would essentially be
dictated by current velocities and construction schedules.

During the initial months of Phase II, the diversion channel must
accommodate both upbound and downbound navigation. At this time, the
flow is expected to be less than 10 000 m³/s and two–way navigation
should be possible. However, as no model test data is available for
two–way traffic, the channel has been assumed to operate as a one–way
section 5 kilometers in length.
Once the temporary lock is completed and for the remainder of Phase II, the following operating procedures are anticipated:

- when the flow is less than 25 000 m³/s, all downbound navigation would move through the diversion channel. Upbound passenger vessels would also use the diversion channel; however, all other upbound traffic would use the lock initially and later the lock and shiplift.

- when the flow exceeds 25 000 m³/s, upbound and downbound traffic would be routed through the lock and shiplift. The assumption of a 25 000 m³/s cutoff for the diversion channel has not been examined in model tests but it is judged to be a reasonable upper limit.

- when the flow exceeds 45 000 m³/s, it is assumed that navigation on the river would be suspended.

At the beginning of Phase III when the diversion channel is closed off, all traffic would move through the lock and shiplift until such time as the reservoir level is raised to approximately El 76. From that time until the reservoir reaches El 130, (approximately 4 to 6 weeks), the shiplift would be the only means of through navigation.

5.1.3 Characteristics of the Yichang—Chongqing Navigation Channel

Except for the section of the river immediately adjacent to the construction site, the construction activity at Three Gorges will not have any significant impact on navigation conditions between Yichang and Chongqing. Completion of the Stage I and Stage II cofferdams will lead to some increase in river levels upstream of the project site. However, the main navigation constraints are located well upstream of the project and as a result are unlikely to be affected by these changes.

Conditions in the river upstream of the Project site will therefore not be materially changed during the construction period. Only when the reservoir level begins to rise in Year 12 (mid-2000) will there be a significant impact on the upstream channel.

5.2 River Operations During Construction

5.2.1 Expected Freight and Passenger Traffic

As discussed in Section 4.2.1, there is a considerable difference of opinion regarding the amount of traffic expected to move through the Upper Yangtze over the coming years. Chinese forecasts for downbound water-borne freight traffic in the year 2000 are as follows:
– YVPO – 10 to 12 x 10^6 t
– Ministry of Communications – 20 x 10^6 t
– Port of Chongqing – 25 x 10^6 t

Upbound freight is estimated at 25% of downbound tonnages.

CYJV’s forecasts for total downbound water—borne freight in the year 2000 range from 3.0 x 10^6 t under the low growth assumptions to 7.4 x 10^6 t under higher growth assumptions. Upbound freight is forecast at 2.1 to 2.2 x 10^6 t. These forecasts are based on the premise that there is unlikely to be a significant change in vessel operating costs during the construction period, and hence that the water share of total inter—regional traffic will be the same as that projected without Three Gorges.

In addition, CYJV has projected river passenger traffic through the region of between 4.1 and 5.2 x 10^6 person trips in the year 2000 of which between 2.3 and 3.0 x 10^6 would be downbound. This implies between 9 and 12 daily downbound transits of passenger vessels if average vessel loadings remain relatively constant. However, if there is shift towards the larger, 1 100 passenger CSC vessels, daily one—way transits would more likely be between 7 and 9.

5.2.2 Vessel Operating Characteristics and Costs

The natural evolution of river operations towards greater efficiency, which was postulated under the "without Three Gorges" scenario (Section 4.2.3), will not likely be significantly altered in the event of a decision to build Three Gorges. Consequently, it is expected that over the period of project construction there will be the same improvement in vessel operating procedures on the river, including reductions in port time and crew costs and an increase in daily operating hours through better communications and traffic control procedures.

Since there is no significant change in the physical characteristics of the river during the construction period, it is not expected that there will be any major change in the type of equipment used by either freight or passenger operators over this time frame. As traffic increases there may be some increase in the average size of tow, but the limits on maximum tow sizes are expected to remain as they are at the present time.

Vessel operating costs over the construction period are therefore expected to decline from existing levels to the levels projected in the "without Three Gorges" scenario; that is, for a 3 x 1 000 t tow:
Existing and Future Barge Cost — No Three Gorges

(Fen per Tkm)

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Year 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chongqing—Yichang</td>
<td>4.9</td>
<td>4.0</td>
</tr>
<tr>
<td>Chongqing—Wuhan</td>
<td>3.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>

5.3 Balance Between Capacity and Demand — Construction Period

5.3.1 Capacity of the Temporary Navigation Facilities

The capacity of the diversion channel, shiplift and temporary shiplock was estimated based on the YVPO/MOC methodology. For the lock and shiplift, the formula used was as follows:

\[
C = \frac{\text{Ave. t/lockage} \times \text{Loaded Lockages/Days} \times \text{Days/Year}}{\text{Adjustment for Random Arrivals}}
\]

The main assumptions used were:

- **Tow Mix**: The Changjiang Shipping Company (CSC) and the Provincial shipping companies will each transport half of the tonnage. On this basis, and using expected tow configurations and capacities for each carrier, the theoretical tonnes per lockage are estimated to be 2 009 t for the lock and 823 t for the shiplift.

- **Operating time**: 22 hours per day, 335 days per year

- **Non—cargo and Passenger Allowances**: Lock capacity includes an allowance for two non—cargo lockages per day, and, as a base case, six passenger ship transits per day each way. Six passenger vessel transits represents two lockages or six shiplift operations. The base figure for passenger ship transits is slightly below the forecast average number but corresponds to the passenger transits assumed by YVPO. Sensitivity of capacity to additional passenger vessel movements was also evaluated.

- **Efficiency of Utilization**: Due to random arrivals, there will be idle time during the operating day. A factor of 1/1.37 is applied to adjust for this idle time. Also, the theoretical tonnes per lockage shown above would be reduced by 15% as a result of variations in tow configurations or loadings. These figures are compatible with generally accepted capacity—utilization factors.

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Flow Limitation: Navigation on the river would be stopped when river flows exceed 45 000 m³/s. This is consistent with current navigation procedures.

All capacity estimates are based on balanced traffic; that is, the same number of movements upbound and downbound. However, tonnage figures are given for one way only. Where the diversion channel is used to pass traffic downstream, the estimate of system capacity is limited to the one-way upbound capacity of the lock and the shiplift. Flow durations, which define the periods in which the diversion channel can be used, are based on 102 years of stream flow at Yichang. These flows are shown for various exceedence percentages in Figure 5.2.

The probable capacities of the temporary navigation facilities at various stages in the construction period are shown schematically in Plate 6.5. These estimates are based on the operating procedures and criteria described above in Section 5.1.2.

During the initial months of Phase II when all traffic must be routed through the diversion channel, capacity is estimated to be 34 000 t per day. This is based on one-way operation of the channel with the direction reversed after every fourth transit.

Once the temporary lock and later the shiplift are brought into service, the capacity varies according to which of the facilities are available for navigation. When the diversion channel is open, capacity is based on one-way operation of the lock and shiplift. When the channel is closed, capacity is based on two-way balanced traffic in the lock and shiplift. When both the channel and lock are closed during the reservoir filling period, capacity is based on two-way operation of the shiplift alone.

Plate 6.4 shows that during most of the construction period, capacity of the temporary facilities will exceed 35 000 t per day or approximately 12 x 10⁶ t on an annual basis. The critical periods for capacity occur when the diversion channel is not available for navigation. This occurs each year of Phase II during the high flow period, and in Phase III when the Stage III cofferdam is being built and when the reservoir is being raised to EL 130. During these critical periods, the temporary lock and the shiplift (available towards the end of Phase II) would be operated two way with balanced traffic. One-way capacity during these periods, calculated on an annual basis and assuming two non-cargo lockages and 6 passenger vessel transits per day, is as follows:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Capacity (t/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shiplift</td>
<td>2.9 x 10⁶ t (8 700 t/day)</td>
</tr>
<tr>
<td>Temporary Lock</td>
<td>6.7 x 10⁶ t (20 000 t/day)</td>
</tr>
<tr>
<td>Combined</td>
<td>10.4 x 10⁶ t (31 000 t/day)</td>
</tr>
</tbody>
</table>
As noted earlier, an allowance for 6 passenger vessel transits per day may not be sufficient to meet passenger demand. Accordingly some sensitivity analysis was carried out to examine the impact of additional passenger vessels. The results of this analysis are shown in Figure 5.3 for the shiplift, temporary lock and combined facilities.

The Figure indicates that if passenger vessels increase from 6 per day to 9, the capacity of the combined facilities would decline from $10.4 \times 10^6$ t to $9.6 \times 10^6$ (29 000 t per day). Capacity of the temporary lock without the shiplift would decline from $6.7 \times 10^6$ t to $6.1 \times 10^6$ t (18 000 t per day).

The above calculation does not take into account the fact that elimination of the shiplift would permit construction of flared approach walls at the upstream and downstream entrances to the temporary lock. The general location of the walls is shown in Plate 6.5. These approach walls would enable vessels to moor close to the lock entrance while awaiting transit, thus potentially reducing the total transit time and increasing the daily lockages.

It should be stressed that all of the above capacity estimates are based on average conditions and make allowances for fog, maintenance, random arrivals, and other delays. Higher capacity could of course be achieved by operating closer to the theoretical capacity but with resultant queues and potentially long waiting times. If these problems are acceptable at least for short periods, the estimates of critical capacity limits during construction would increase.

5.3.2 Capacity of the Yichang—Chongqing Navigation Channel

As noted in Section 5.1.4, it is not expected that there will be any significant change in the physical characteristics of the channel upstream of the Project during the construction period. The existing constraints to navigation, including winching stations, one-way sections, and high velocities will continue to impose limits on the capacity of the river. It is anticipated, however, that as a result of higher traffic demand and potential improvements in traffic control procedures, there will be some shift towards longer operating hours. In addition, higher demand may lead to a higher portion of large tows in the overall traffic mix.

If the average tow mix used to calculate the capacity of the temporary navigation facilities is applied to the expected conditions on the river, average cargo per tow would be approximately 1 000 t and the capacity of the upstream channel would be $9.2 \times 10^6$ t per annum excluding passenger vessels. Six passenger transits per day would reduce this capacity to $7.5 \times 10^6$ t. If higher average tonnes per tow were assumed, channel capacity would increase correspondingly. However the capacity of the temporary navigation facilities might not increase in the same proportion since tonnes per lockage is constrained by the physical dimensions of the
CAPACITY OF TEMPORARY NAVIGATION FACILITIES

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lock and shiplift chambers and by depth limitations in the upstream channel.

5.3.3 Adequacy of Capacity for Proposed Facilities

It would appear from the above analysis and from the forecasts of freight and passenger traffic that, if the CYJV forecast traffic levels are achieved, (i.e. 3.0 – 7.4 x 10^6 t by the year 2000) the temporary navigation facilities proposed by YVPO will provide sufficient capacity. If the YVPO forecasts of 10 – 12 x 10^6 t of freight and 6 daily passenger vessels are achieved, there could be some temporary capacity problems during critical capacity periods when the diversion channel is out of service. These problems would be aggravated if an above-average share of annual traffic attempts to pass through the facilities during this time.

If MOC or Port of Chongqing forecasts are realized, (20 and 25 x 10^6 t respectively), capacity problems through the temporary facilities would be severe. However, these traffic levels would also lead to severe capacity problems in the upstream river channel. With the navigation constraints which will continue to exist above the Project site, the channel could not accommodate the projected traffic volumes unless average tow size increases to the 3 000 t range (see Table 3.5). This is not likely to occur unless provincial companies invest in substantially larger equipment, or CSC captures virtually all of the traffic and moves it in maximum-size tows.

Under the CYJV forecasts, it would also appear that traffic could be accommodated through the temporary facilities using only the diversion channel and the temporary lock, with the exception of the 4 – 6 week period when the reservoir is being raised. Even at the higher YVPO forecasts, careful traffic management by shipping companies to ensure that the majority of cargo is moved while the diversion channel is open, would allow traffic to be handled without the shiplift throughout Phase II and the early part of Phase III, although above-average delays would undoubtedly occur during Phase III when the temporary lock would be operating above its practical capacity.

If the shiplift were not included in the temporary facilities, there would be substantial construction cost savings. Offsetting these, however, would be the costs imposed by having to suspend navigation on the river during the period when the reservoir level is being raised from 76 m to 130 m. The extent to which these costs outweigh the capital cost savings will depend on whether there are available interim alternatives to navigation, what the cost of the interim alternatives would be and what level of traffic would be affected. The economic aspects of these trade-offs under different traffic forecasts are discussed in Section 5.4.
5.4 Design and Operating Alternatives

While the YVPO proposals were generally considered to be appropriate in terms of the required standards of the navigation sector, it was felt that some economies might be achieved, through modifications in design or in operating procedures, without unduly compromising the navigation standards. Four possible modifications to the above proposals appeared to have some potential viability and were therefore considered as part of the overall feasibility analysis. These were:

1. widen the diversion channel;

2. change the directional operating rules for the temporary navigation facilities;

3. increase the height of the temporary lock; and

4. eliminate the shiplift, limiting the temporary facilities to the diversion channel and the temporary lock.

5.4.1 Widening of the Diversion Channel

The diversion channel as initially proposed, would have a width of 350 m. While this would meet the standards required for temporary navigation facilities, a wider channel would reduce channel velocities, improve navigation conditions, and extend the period of time when vessels could transit the channel. Consequently, consideration was given to the technical viability of widening the channel to 400 m.

While this added width would provide some improvement in the navigation conditions, it would also mean that excavation quantities, Stage III cofferdam quantities, and roller compacted concrete cofferdam quantities would all be increased by approximately 15% (depending on the selected bottom elevation). This would both increase construction costs and aggravate an already difficult construction schedule.

Widening the diversion channel to 400 meters would be more attractive if, on the basis of the resultant increase in its capacity and operating period, the temporary lock could be omitted. However, even with a widened diversion channel, there would be a period of approximately 3 months in each year of Phase II when the diversion channel could not be used and traffic would have to be handled exclusively by the shiplift or, if capacity were insufficient, either stockpiled or portaged around the site. In addition, the diversion channel would not be available during the five to six month period when the Stage III cofferdam is being built (December of Year 11 to May of Year 12), thus extending the time when the shiplift would be the only means of through navigation.
Given the relatively small dimensions and limited capacity of the shiplift, it is unlikely that the shiplift alone could provide a satisfactory level of service during the periods when the diversion channel is not available. Thus, the temporary lock would be required whether the diversion channel is widened or not. In view of the increased construction costs and scheduling problems mentioned above, it was concluded that widening the diversion channel would not be justifiable.

5.4.2 Two-Way Operation of Temporary Facilities

A second modification which was considered involved operating the facilities on a two-directional rather than one-directional basis when flows are less than 25,000 m$^3$/s. At these flow levels, it would be possible to use the diversion channel for both upbound and downbound traffic. This would also permit a balanced flow of upbound and downbound traffic through the temporary lock and shiplift. However, since it is questionable whether simultaneous two-way traffic in the diversion channel would be practical, it was recommended that the preferred arrangement would be to operate the diversion channel one-way downbound and the lock and shiplift one-way upbound. This offers the combined advantages of simplicity, safety and energy efficiency as well as substantial capacity during the period when all three facilities are available to navigation.

5.4.3 Increased Height for Temporary Lock

A third modification which was evaluated was to increase the height of the temporary lock coping from El 78.7 to El 98, thus increasing the effective level by approximately 20 meters. This change was proposed because there appears to be a possible risk of delays in completion of the Stage III RCC cofferdam, and the higher lock would permit operation through the summer months with the diversion outlets open and the diversion channel closed.

The construction schedule calls for closing off the diversion channel late in year 11 (1999) and completing construction of the RCC cofferdam by May of the following year. Once the cofferdam is substantially complete, the diversion outlet gates in the dam can be closed, the reservoir can be raised to 130 m and navigation can be routed through the permanent locks. However, the diversion outlet gates can be closed only if the river flows are 20,000 m$^3$/s or less. If the cofferdam is only partially completed in May, the diversion outlet gates could not be closed until the end of the flood season (probably October or November) and it would not be possible to raise the reservoir to the point where the permanent locks could be used. Navigation would therefore have to continue to use the temporary lock.

However, once the diversion channel is closed off, the increased flows associated with the flood season would cause the water level behind the dam to rise well above the 76.7 meters which can be accommodated by the temporary lock. If this occurs, the temporary lock would have to be
closed with stoplogs and navigation would have to be suspended (or all routed through the shiplift if the lift were built) for as much as 5 to 6 months until flows dropped to the point where the diversion outlets could be closed and the reservoir filled.

Increasing the height of the temporary lock coping to 98 metres would allow the lock to operate up to a flow of 45 000 m$^3$/s, (upper pool El 96), which is the maximum flow condition for navigation in the Upper Reach of the river. Thus, if the diversion outlets could not be closed on schedule, the temporary lock would be able to handle the traffic throughout the summer navigation season. If the cofferdam is completed as scheduled, the additional height of the temporary lock would serve to shorten the period when navigation is suspended during the filling of the reservoir.

Raising the lock coping from 78.7 to 98 meters would not result in a major increase in quantities or cost. The main items which would be affected are:

- concrete walls and gate areas,
- height of the mitre gates,
- larger, more sophisticated filling valves,
- a new floor filling system, and
- modification to the lintel arrangement at the dam.

Accordingly, in order to offset the risk that navigation might have to be suspended if completion of the RCC cofferdam is delayed, it is recommended that the design of the temporary lock be modified and the coping elevation increased to 98 metres.

5.4.4 Elimination of the Shiplift

The shiplift and temporary lock would be served by a common downstream approach channel, and the lift would be an integral part of the left bank gravity dam. From a technical point of view, excluding the shiplift from both the temporary and permanent designs would not present any difficulties. However, if it is proposed only that the shiplift be deferred until some future date, provision for its later construction should be incorporated into the design and original construction work.

From the operating perspective, eliminating the shiplift would mean that, during Phase II, all traffic must be handled by the temporary lock and diversion channel, when the latter is available. It would also mean suspending navigation during the period in Phase III when the reservoir is being raised to El 130 and the temporary lock is out of service. Since the shiplift is also intended as part of the permanent navigation facilities, the impacts of omitting it from the design extend beyond the construction stage. For this reason and also because of the complexity of the issues involved, a detailed analysis of the implications of omitting the shiplift
was carried out. The findings of this analysis, from the viewpoint of the temporary navigation facilities, are summarized below. The findings regarding the shiplift's effectiveness as part of the permanent facilities are discussed in Section 7.7.1. A more detailed description of the analyses and results is provided in Appendix E.

1 Expected Role of the Shiplift

The shiplift proposed in the YVPO design has a dual function. As part of the temporary navigation facilities, it supplements the capacity of the diversion channel and temporary lock during the latter part of Phase II of construction. At the beginning of Phase III, it serves for approximately 6 months as a supplement to the temporary lock, and then serves as the only means of through navigation for a 4 to 6 week period while the reservoir is being raised to EL 130.

Once the reservoir is raised and the permanent locks are operating, virtually all freight traffic would be routed through the locks during the initial years, since the shiplift, with its relatively small chamber, is not well suited to handle the typical tows operating on the river. During this period, the shiplift's main role will be to provide fast transit of passenger vessels, since the permanent locks would have sufficient capacity to meet all demand at this time and the shiplift's capacity would not be required.

As demand increases to approach the capacity of the permanent locks, the shiplift will again contribute to the capacity of the system by relieving the permanent locks of the need to carry passenger vessels. The capacity equivalent of this contribution, and hence the shiplift's contribution to extending the life of the facilities, will depend on the average freight tonnes which can be handled per lockage given the fleet mix.

2 Effectiveness as a Temporary Structure

The study of capacity/demand balance during the construction period found that, under the CYJV and the YVPO demand forecasts, traffic could be accommodated by the temporary lock and the diversion channel until such time as the temporary lock had to be closed in order to raise the reservoir. The key focus of the shiplift analysis was therefore on the 4 to 6 week period when the reservoir is raised and the shiplift provides the only means of through navigation. Several alternatives for meeting transportation demand during this period were postulated and the associated costs of these alternatives were compared with the savings obtained by not building the shiplift. Among the alternatives examined were overland movement of cargo by road or by rail, stockpiling of non-perishable cargo prior to the closure period, and construction of a bypass road around the project site to handle passenger traffic.
Details of the analysis are provided in Appendix E. The key finding was that, with a two month closure period, the shiplift was the most costly of the alternatives examined for the CYJV forecast traffic levels. For the YVPO forecast traffic levels, the shiplift option was more costly than all of the alternatives except the option of diverting all traffic to trucks.

Maximum savings associated with omitting the shiplift ranged from $124 \times 10^6$ yuan to $215 \times 10^6$ yuan. If the closure extended to six months, the shiplift still failed to represent a cost-effective solution, although the option of diverting all traffic by road was more costly than the shiplift for all forecast traffic levels. In all cases, stockpiling non-perishable cargo and using overland modes to move perishables and passengers during closure was the lowest cost option, yielding savings of between $118 \times 10^6$ yuan and $270 \times 10^6$ yuan.

3 Conclusions

The above analysis suggests that construction of the shiplift as part of the temporary facilities cannot be justified on economic grounds. During the construction period when navigation would have to be suspended without the shiplift, there appear to be reasonable alternatives to the shiplift which involve significantly lower overall costs.

It is recognized that there are other considerations associated with the decision to build the shiplift which are difficult to quantify and hence cannot be incorporated into an economic analysis. These considerations are particularly relevant during the construction stage, and include factors such as the inconvenience to users associated with suspending navigation, congestion on other modes if traffic is diverted from the river, and logistical problems associated with providing alternative means of transport. However, on the basis of measurable cost-effectiveness, the shiplift cannot be justified and consideration should be given to excluding it from the final design.

5.5 Summary and Conclusions

During the Three Gorges construction period, navigation on the Yangtze will likely develop in much the same manner as would be expected without the project. River conditions will remain virtually unchanged with the exception of the area around the construction site. Some evolution in vessel operations is expected over the period but will not differ from the changes which would occur without the project.

At the construction site, the facilities and procedures proposed to handle ongoing navigation are suitable both in terms of design and capacity. Two modifications to the proposed facilities are recommended: increase the height of the temporary lock to El 98; and omit the shiplift.
6. NAVIGATION CONDITIONS AFTER PROJECT COMPLETION

Based on the schedule adopted for the CYJV Recommended Project, the reservoir will be raised to El 130 in Year 12 of construction (year 2000). This level will be maintained until May of year 16 (2004) when the reservoir will be raised to FCL and thereafter it will be operated in accordance with the seasonal operating pattern shown in Figure 6.1. This operating pattern requires that the reservoir generally be held at higher NPL during the dry winter season, and drawn down to FCL during the summer months to provide flood protection and flushing of sediment loads. On occasion during the winter season, however, it will be necessary to draw the reservoir down below NPL in order to meet the requirements of power generation or discharge rates below Gezhouba.

Throughout this period, navigation on the river will be routed through the permanent navigation facilities at the project site. Upstream of the project, vessels will pass through a reservoir whose length and conditions will vary depending both on the season of the year, the selected NPL and FCL, and the reservoir operating pattern. The following sections describe the expected long-term pattern of navigation on the Upper Yangtze once the project has been completed and the permanent reservoir has been established.

6.1 Navigation Facilities at Three Gorges Project

6.1.1 Description of Proposed Facilities

The permanent navigation facilities at the dam site, as proposed by YVPO, consist of a system of twinned navigation locks measuring 280 m x 34 m x 5 m each, and the shiplift (120 m x 18 m) which is to be constructed as part of the temporary navigation structures.

For the locks system, two basic options are available: flight locks or separate locks with intervening reaches. Plate 6.6 shows the general arrangement for twin five-stage flight locks. Plate 6.7 shows the general location of four flight locks and a two and three separate locks system.

The number of locks required under each alternative is a function of the chosen NPL. YVPO proposed to build four-stage flight locks for NPLs 150 and 160, and five-stage flight locks for NPLs 170 and 180. Proposals for separate lock systems comprised two separate locks for NPL 150 and three separate locks for NPL 160 and 170.

The technical aspects of these proposals have since been reviewed and the proposed flight-lock arrangement modified somewhat. Essentially, it was judged that with an NPL in the 160 m range, five-stage flight locks would provide a more satisfactory arrangement that was only moderately in excess of world experience in terms of hydraulic conditions. Details of the technical assessment are provided in Volume 4, Section 10.5.
NOTE

- - - - Target water levels

- - - - Average actual over 44 years of simulated operation.
The general arrangement and the location of the shiplift, shown in Plate 6.7, are similar for all NPLs. The main impact of NPL is on the height of the shiplift structure. As the assumed NPL rises, the machinery room, supporting columns and upstream gate/stop log arrangement of the shiplift will all have to be correspondingly higher.

From a technical perspective, the proposed shiplift was considered feasible. Volume 4, Section 10.3 discusses the technical viability and reliability of the shiplift in greater detail. Economic viability of the shiplift is discussed in Sections 5.4.4 and 7.7.1 of this report.

6.1.2 Comparison of Alternative Lock Arrangements

The differences between the flight locks and the separate lock schemes in terms of technical viability are minimal. Thus, a choice between them must be based on a comparison of capacity, operating and cost considerations.

.1 Capacity

The capacity of three twinned separate locks is estimated to be slightly higher than the capacity of the five-stage flight locks. However, the differences are small and well within the range of accuracy of the demand, fleet mix and capacity estimates. In addition, the short reaches between locks in the separate lock scheme may complicate traffic management, particularly when lockages consist of several vessels. Congestion in the reaches and different vessel speeds make it difficult to keep vessels together and may cause an increase in lock cycle time and a decrease in the practical capacity of the separate locks system.

.2 Operating Considerations

In terms of operations, differences between the two systems are small. Operating advantages of the separate locks scheme include a reduced hydraulic head, greater flexibility to accommodate traffic if one of the locks is out of service, and greater separation between the approach channels and the dam. Disadvantages include congestion in the short reaches between locks, and traffic management problems in attempting to keep multi-vessel lockages together as they move from one lock to the next. Lock entry times could also be longer, particularly if the locks are operated in both directions rather than one way.

The main operating advantage of the flight locks is the ease with which multi-vessel lockages can move through the system. Also while the hydraulic head is higher than for the separate lock scheme, it diminishes more rapidly. Although the approach channels for the flight locks are closer to the dam site, required navigation conditions can be met with the proposed navigation dike arrangements.
3 Construction Cost

On a cost basis, the twinned separate lock alternative is estimated to be some 21% more expensive than the flight lock scheme. The difference is attributable to the requirement for side pondage to control surges in the intervening channels, and the additional excavation quantities associated with the separate locks scheme.

4 Other Considerations

The separate lock alternative also interferes with site access during construction and with a number of the proposed facilities at the construction site. This interference could increase the construction cost of other facilities.

However, the separate locks scheme would allow greater flexibility in terms of staged construction. If the capacity of twin locks is not required during the early years of the project, a single set of separate locks could be built initially and a second set added at a later date as demand increases. The cost implications of staged construction are discussed in Section 7.7.2.

5 Summary

The flight lock and separate lock alternatives are very similar in terms of both capacity and operating considerations. The primary difference is in capital cost, with the twin separate lock scheme being some 21% more costly than the flight lock alternative. Unless there is a clear indication that the separate locks scheme could be constructed in two stages with the second stage deferred sufficiently to offset the higher cost, the flight locks alternative is the least costly option. Even if the cost of the separate lock scheme were lower due to staged construction, the flight locks might still be preferred as they would interfere less with the construction of other facilities.

6.2 Navigation Conditions in the Reservoir

The construction of Three Gorges Project will have a substantial impact on the navigation conditions in the Upper Reach of the Yangtze. Under all proposed schemes, a large part of the channel between Yichang and Chongqing will be incorporated into the Three Gorges Project reservoir during both dry and flood seasons. However, under the range of reservoir schemes being considered, there remains a portion of the river between Yichang and Chongqing whose future condition will vary depending on the season and the selected NPL/FCL/PDL combination. This fluctuating backwater region is shown in Plate 6.8.

The following sections deal with river conditions, first under the alternative NPL schemes (150, 160, 170 and 180), secondly under the
various FCL options (135, 140 and 145), and finally at lower dry-season reservoir levels which might occur during the final years of construction or during very dry years when the reservoir is pulled down to PDL (power drawdown level) in order to maintain power supply.

The physical characteristics described in the following sections were derived from a number of sources, including:

- output from the HEC–2 Water Surface Profiles model of the river under alternative reservoir level/flow combinations;
- navigation charts of critical sections of the river;
- information derived from CYJY sedimentation studies;
- review of previous work carried out by YVPO; and
- discussions with representatives of the Yangtze Navigation Administration and the Ministry of Communications.

NPL and FCL conditions are described under average dry-season and flood-season flow rates for the river. Dry season flows are based on a 44-year average of monthly flows for December through April, adjusted to simulate upstream storage which is expected to be constructed on the Yangtze and its tributaries. Flood season flows are based on average historic flows for July, August and September with the same adjustment for upstream storage capacity. Shoulder season conditions (currently occurring during October, November, May and June) were examined and found to approximate conditions mid-way between dry and flood seasons. Accordingly, for the two months of transition between NPL and FCL, an average of dry-season and flood-season conditions was assumed. Further details on hydraulics and hydrology are given in Volume 4.

6.2.1 NPL Conditions

The physical characteristics of the river were examined under four alternative NPL scenarios. Average conditions in terms of velocities and channel constraints which would be expected during the NPL period are described in the following sections. Note that distances conform to the navigation charts of the river and measure the navigation distances above Yichang rather. They do not, therefore, conform directly to the hydraulic models which are measured at the mid-point of the river in kilometers above the dam.

1 NPL 150

At NPL 150 under average winter flow conditions, the reservoir effect of Three Gorges Project will extend approximately 600 km above Yichang, to a point some 20 km upstream of Changshou. Mean velocity in the channel from Yichang to Chongqing, including the
section above km 600 which will still be in natural condition, is expected to average 1.5 km/hr (0.4 m/s).

With the reservoir at El 150, almost all of the dry-season navigation constraints below Changshou will be eliminated. This includes all of the existing winching stations as well as the one-way sections numbered 1 - 29 in Table 2.1. Conditions at sections 30 and 31 (Wangjiatang and Fengheshang) will be improved somewhat, but if flows are low they may impose some constraint on navigation. The one-way sections through Luoqi (km 604), Daxingchang (km 639.5) and Tongluoxia (km 644), however, will not be affected at this reservoir level and the river will remain in natural conditions. In addition, the one-way section at Sanjiaoqi (km 669.7) just downstream of Chongqing’s port facility at Jiulongpo will be unaffected by the reservoir.

.2 NPL 160

At NPL 160 and average winter flow conditions, the reservoir effect will reach to approximately km 666, just upstream of the junction of the Yangtze and the Jialing. Mean dry-season velocity in the channel between Chongqing and Yichang will be about 0.68 km/hr (1.91 m/s). Two-way traffic should be possible up to Chaotiamen (km 660), one of the main ports at Chongqing, but the reservoir will have little impact on the Sanjiaoqi section around km 670, and two-way access to Jiulongpo would continue to be constrained by this section. Output from the HEC-2 model, together with navigation chart data, indicates, however, that once the flow in the upper river reaches 3,000 m³/s, which is equivalent to approximately 4,000 m³/s at Yichang, one-way operation through Sanjiaoqi is not required and two-way navigation to Jiulongpo should be possible.

.3 NPL 170

At NPL 170, the reservoir effect will extend to approximately km 697, 25 km above the port of Jiulongpo. Mean velocity in the channel from Chongqing to Yichang is estimated at 0.56 km/hr (0.16 m/s) during the NPL season. If the reservoir is maintained at this level, it should be possible to provide full two-way access up to Jiulongpo throughout the winter season. According to navigation data and the output from the HEC-2 model, the water level at Jiulongpo will be at least 6 meters above chart level when the reservoir is at 170 m. The navigation charts provided by YVPO indicate that, provided the surface is 3 meters above chart level, two-way operation to Jiulongpo should be possible.

.4 NPL 180

At NPL 180, the reservoir will extend to around km 720, 60 km above Chongqing. All obstructions between Yichang and Jiulongpo should be
eliminated for the duration of the NPL season. As with the 170 NPL scenario, mean dry-season velocities between Chongqing and Yichang are estimated at 0.56 km/hr.

6.2.2 FCL Conditions

River conditions during FCL season (most probably the months of June through September) were examined for three reservoir levels: 135, 140 and 145 meters. Again distances are measured above Yichang, and reservoir length is defined under flows of approximately 25 000 m³/s.

.1 FCL 135

At FCL 135 and average flood season flows, the Three Gorges Project reservoir effect would extend to around km 485 above Yichang, just above the community of Fengdu and approximately 175 km downstream from Chongqing. Due to the high average flows during this period and the long section of river which will remain in its natural state, the average flood season stream velocity between Chongqing and Yichang is estimated at 5.2 km/hr (1.46 m/s).

The FCL 135 reservoir should eliminate the need for winching in the Upper Reach of the river. In addition, many of the one-way control sections will no longer be necessary. However, it will not be possible to eliminate all one-way controls below Chongqing. At 135 FCL, at least two sections will have to be operated one-way throughout the FCL period: Huangcaxia at km 573.9 and Tongluoxia at km 644.0.

The Tongluoxia one-way section is the longest, with operations controlled from km 644.0 to km 645.2. In addition, the combination of narrow channel, tight (720 m) bend radius, and high velocities will limit tow size to a maximum of 3 - 4 x 1 000 tonne barges. Two other sections of the river will probably be limited to one-way operation for part of the flood season: Zaomenzi at km 494.2 and Huatan at km 518.5.

.2 FCL 140

At FCL 140, the reservoir effect will reach to approximately km 520 above Yichang. Because of the longer reservoir, average velocities between Chongqing and Yichang are estimated at 4.9 km/hr (1.36 m/s). However, operating conditions at Huangcaxia and Tongluoxia will not be affected by the reservoir, and one-way limitations will continue to apply throughout the FCL season.

.3 FCL 145

At FCL 145, the flood-season reservoir effect will reach approximately km 580, and average velocities in the channel between Chongqing and Yichang will decline to 4.3 km/hr (1.2 m/s). As with
the 135 and 140 FCLs, however, operating constraints will remain in effect through the Huangcaxia and Tongluoxia sections, limiting traffic to one-way movement and limiting tow size to a maximum of 3 – 4 barges.

These three FCLs were the only ones which were examined in detail from the navigation viewpoint. It should be noted, however, that even at FCLs as high as 160 m, operations would still be restricted through the Huangcaxia and Tongluoxia sections. Output from the HEC–2 model indicates that velocities would continue to exceed 4 m/s and the channel width/bend radius problem would not be significantly improved. It therefore appears that it is not feasible, within the range of viable FCLs, to eliminate or even substantially mitigate flood season operating constraints in the Upper Reach of the river.

6.2.3 Critical Levels for Navigation

While the NPL and FCL conditions described above will represent navigation conditions during most of the year, there will be occasions when the combined effects of river flow and reservoir stage will create constraints to navigation which have not been covered above. These occasions could arise during the winter season in dry years when the reservoir cannot be maintained at NPL throughout the period or during the shoulder season when the reservoir is being drawn down or filled.

1 Winter Season

Problems during the winter season are likely to occur during dry years when NPL cannot be maintained either as a result of power generation requirements, the need to maintain minimum flows in the channel below Gezhouba or a combination of the two. Analysis of historic flow statistics at 7 dry-season month-ends over 44 years indicates that the reservoir could have been maintained at NPL 150 in 62% of the cases (191 out of 308 observations) and could have been held at or above 145 for 83% of the time. Levels below 135 would only have occurred in 3% of the observations.

With an NPL 160 scheme, the 160 level could have been maintained in 60% of the cases and levels of 155 m or higher could have been maintained 85% of the time. The probability of maintaining an NPL of 170 m was somewhat lower (42%). However, with NPL 170, levels in excess of 165 could have been achieved in 70% of the cases, and levels above 160 on 87.5% of the occasions.

2 Shoulder Seasons

Problems in the shoulder seasons during the drawdown or refilling stages of the reservoir cycle are more likely to occur if the change in level takes place when flows are low. This could arise either in an unusually dry year or during a normal year if drawdown is begun
too early in the rising stage of the river or filling is delayed too long after the flood season. The average daily flow statistics which were presented in Figure 5.2 provide a point of reference regarding the timing of increasing and decreasing flows.

The effects of low—flow/low—reservoir conditions can best be described by examining critical flow/reservoir stage combinations in relation to navigation constraints in the variable backwater region. Figures 6.2 and 6.3 show the inter—relationship between these navigation constraints and the stage level of the river. These diagrams show the river stage at two flow levels and under two alternate reservoir scenarios (135 and 145 m).

In the figures, the vertical bars represent the range of water surface elevations at which the various navigation constraints apply. Thus Beiliang (far left) is a problem when the water surface elevation is 137 m or less. Huatan (fourth from the left) is a constraint at surface elevations between 141 and 151 m.

The sloping profiles on the figures show the actual water surface elevations at various flow levels. The lower line ("Chart Datum") is the dry season surface elevation which corresponds to 2.9 m of depth throughout the navigation channel. The upper profiles (Q = 10 000 and Q = 20 000) represent water surface elevations corresponding to reservoir conditions with flows of 10 000 and 20 000 m³/s at Yichang. Flows above or below these levels would generate correspondingly higher or lower surface elevations. Similarly, higher or lower reservoir levels would affect both the level and the shape of water surface profile.

During low flow periods (i.e. during the winter NPL season when flows at Sandouping are in the 5 000 m³/s range and flows above Chongqing are in the order of 3 000 m³/s), critical levels for navigation begin at a water level of 158 m. Below this level, the one—way section at Daxingchang (km 639.5—641.5) comes into effect, with velocities which could potentially limit low—powered traffic. When the water level falls to 155 m, two additional constraints begin to affect operations: Luoqi (km 604—606.2) and Wangjiatan (km 582.2—587.7). Both of these sections could impose draft limitations on tows and could limit maximum tow size.

If the assumed water level is further reduced, additional one—way sections come into effect: the area around the shoal at Tuerba (km 505—508.6) which comes into effect at level 141 m and the Beiliang section just above Fengdu (km 483—486) which affects operations at level 137 m. However, both of these sections impose limits which are less severe than those at Wangjiatan/Luoqi and hence would not further constrain tow size or capacity.
WATER SURFACE ELEVATIONS
AND ONE WAY SECTIONS
FLUCTUATING BACKWATER REACH
FCL 135

Volume 6
FIGURE 6.2
WATER SURFACE ELEVATIONS
AND ONE WAY SECTIONS
FLUCTUATING BACKWATER REACH
FCL 145

- 6-11 -

Volume 6
FIGURE 6.3
At the higher flows pertaining in the shoulder season, (i.e. approximately 10 000 – 20 000 m³/s of flow at Sandouping), the first potentially critical section which could come into effect is the one-way reach through Wangjiatan. If flows are less than 15 000 m³/s and reservoir level is drawn down below 155 m, one-way movement will be required through this reach. Other critical sections would include Huatan (km 518.5–519.4) where a shoal constrains operations between water levels 141.5 and 151.5 meters, corresponding to natural flows of 10 000 – 30 000 m³/s.

The one-way sections at Tuerba and Beiliang are also potential constraints during shoulder season. If flows are less than 15 000 m³/s and the reservoir is drawn down to 141 or 137 m respectively, one-way operations would be required.

6.3 Conditions in the Middle Reach of the River

The Three Gorges Project is also expected to have some impact on navigation conditions in the Middle Reach of the river at and below Yichang. The specific areas of interest from the navigation perspective are:

- the impacts of increased dry season flows through the shallow sections of the Middle Reach between Shashi and Chenglingji;
- the effects on these shallow sections of daily fluctuations in flows associated with the peaking operation of the Three Gorges Power Plant;
- the effect of peaking operations on water depths over the locks at Gezhouba, particularly in light of the river degradation likely to be caused by reduced sediment loads; and,
- the effect of reduced sediment loads on shoal formation and sedimentation below Shashi.

6.3.1 Effect of Increased Dry Season Flows

One beneficial impact of the Project is the increase in dry-season flows as a result of flow regulation. Several sections of the Middle Reach experience depth problems during low flow periods either as a result of normal channel conditions or sediment-related shoal formation. Problems are most prevalent in the section between Shashi and Chenglingji (km 130 to 440 below Yichang) and in some areas below Chenglingji.

These depth problems would be alleviated by the higher minimum flows once Three Gorges Project is operational. However, higher flows in the Middle Reach are not solely attributable to Three Gorges Project, as a number of water control projects will be constructed further upstream over
the next two decades which will also provide a substantial measure of dry—season flow control.

Although the basic benefit of higher dry—season flows cannot be attributed to Three Gorges Project it has been suggested that differences in the dry—season flows associated with alternative NPL/FCL/PDL scenarios could lead to significant differences in navigation conditions, and hence in navigation benefits, in the Middle Reach.

It was initially indicated that the Ministry of Communications required a flow of 5 000 m$^3$/s below Gezhouba in order to maintain required navigation depths (3.5 metres) in the downstream channel, and 3 200 m$^3$/s in order to achieve the current minimum of 2.9 metres depth. Since all of the NPL/PDL scenarios examined provide a daily average flow of at least 5 000 m$^3$/s, it was presumed that no incremental benefit accrued as a result of greater power/navigation storage. Figures which have recently been received suggest, however, that flows must exceed 5 000 m$^3$/s if downstream channel depths are to be maintained at 3.5 metres. This would imply a benefit from the higher flows associated with larger power/navigation storage, up to the point where discharges meet the depth requirements for the navigation channel.

CYJV has not had the opportunity to fully review the implications of this information. Consequently, it is not possible at this stage to draw definite conclusions regarding the extent of the downstream navigation benefit associated with higher storage volumes or the nature and cost of alternative measures for alleviating downstream depth problems.

6.3.2 Effect of Peaking Operations on Middle Reach Shallows

In terms of potential navigation problems in the Middle Reach of the river as a result of Three Gorges Project, there is a concern that operation of the Three Gorges and Gezhouba power plants to serve peaks in demand during the dry season could lead to low flows and shallow depths in the river at certain times of the day. This could be especially critical in the shallow sections of the river between Shashi and Chenglingji.

It is possible, however, to get the full peaking benefits at the Three Gorges Project with re—regulation at Gezhouba such that the minimum discharge is 3 200 m$^3$/s and the 24 hour average discharge is slightly greater than 5 000 m$^3$/s (based on the river regulation expected in the year 2005). At a distance of 50 km downstream of Gezhouba, the variation in water levels associated with the variations in discharge during the day is almost fully attenuated, and daily water levels would fluctuate only minimally around the level that corresponds to a release of 5 000 m$^3$/s at Gezhouba. It would therefore appear that the operation of the power plants for peaking would not significantly affect the ability to meet the required navigation standards for river depth between Shashi and Chenglingji.
6.3.3 Effects of Reduced Sediment Load

1 Navigation at Gezhouba

Another concern is that reduced sediment loads in the river may lead to degradation of the river bottom just below the Gezhouba dam, causing water levels to drop below those required to provide adequate depth over the sills at Gezhouba locks. This problem would be aggravated by the low flows associated with peaking operation of the power plants.

Although model studies of river degradation have not yet been completed by the Chinese, preliminary model tests (IWHR and YSRI) indicate degradation below Gezhouba dam of as much as 0.8 after 10 years and 1.5 m after 30 years. (Volume 6, Section 11.6.1)

Under present conditions, a steady state flow of 3 200 m$^3$/s – the minimum flow during peaking operations – would provide a minimum water level of 39.2 m at Gezhouba. However, with the transient conditions during a 24-hour peaking cycle, the lowest level would be 39.5 m (Figure 7.12 of Volume 4). With this water level, the depth over the lock sills would be as follows:

<table>
<thead>
<tr>
<th>Lock 1</th>
<th>Sill Elevation</th>
<th>33.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Depth</td>
<td>6.0 metres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lock 2</th>
<th>Sill Elevation</th>
<th>34.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Depth</td>
<td>5.5 metres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lock 3</th>
<th>Sill Elevation</th>
<th>35.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Depth</td>
<td>4.0 metres</td>
</tr>
</tbody>
</table>

With 1.5 metres degradation, these minimum depths would be reduced to 4.5, 4.0 and 2.5 metres respectively. Since a vessel entering or leaving the locks requires approximately 1 metre under the hull to allow for squat, maximum vessel draft would be limited to 3.5 metres through Lock 1, 3.0 metres through Lock 2 and 1.5 metres through Lock 3. The existing 1 000 tonne CSC barges and the CSC passenger vessels both have a draft of 2.4 metres and could therefore be accommodated in either Lock 1 or 2. Proposed 2 000 tonne barges, however, have a draft of 3.1 metres and would therefore be restricted to Lock 1 during the hours that minimum water levels occur.

Possible solutions to these problems include: increasing the minimum flow from 3 200 to 5 000 m$^3$/s; building downstream river control structures to increase the tailwater elevation at Gezhouba; using more regulating storage at Gezhouba; and implementing operating controls or procedures at the Locks during the low-water periods.
Increasing the minimum flow requirement to 5000 m³/s would substantially reduce the peaking ability of the Three Gorges power plants and an estimated $1.2 \times 10^9$ yuan in gross power benefits would be lost. Downstream river control structures, although not as yet designed or costed, would likely be far more cost-effective in present-value terms.

The probable least-cost solution, however, would be to institute special operating procedures during the hours of low-flow. These would include giving priority at Lock 1 to loaded, deep-draft vessels, routing small and in-ballast vessels through Lock 3 where possible, and using helper tugs or imposing speed constraints on vessels moving into and out of the locks so that squat is reduced or eliminated.

2 Navigation Downstream of Shashi

The preliminary model tests indicate that the reduced sediment load in the river would provide some natural increase in depths through the shallow sections of the Middle Reach since the degradation continues well downstream of Gezhouba. This may serve, in part, to alleviate depth problems through the Shashi—Chenglingji section and may reduce problems of shoal formation below Chenglingji. However, the degradation effect attenuates as the distance from Gezhouba increases, and hence the depth improvement through the critical sections is unlikely to be significant.
7. OPERATIONS, COSTS AND CAPACITY — WITH THREE GORGES

7.1 Expected Freight and Passenger Traffic

As noted in Section 4.2.1, forecasts of future freight traffic on the river have been prepared by the Ministry of Communications, YVPO, and the Port of Chongqing. The forecasts of these various agencies for traffic in the year 2000 varied substantially. For the year 2030, however, all three groups reached similar estimates of approximately $62.5 \times 10^6$ t of river traffic: $50 \times 10^6$ t downbound plus $12.5 \times 10^6$ t upbound.

The CYJV forecasts of demand for water-borne traffic in 2030 range from 19 to $30 \times 10^6$ t, with downbound freight accounting for between 13.6 and $21.9 \times 10^6$ t respectively. This is based on forecasts of demand for total inter-regional freight (including both the water and rail modes) of 36.2 to $55.7 \times 10^6$ t, and on the modal splits which are expected if Three Gorges is built.

These expected modal splits are as follows. If Three Gorges Project is constructed, it is assumed that the water mode will continue to capture traffic currently moving by river and also any growth in these movements. It is also expected to capture all of the traffic associated with resource development in the reservoir region. "New" inter-regional traffic (i.e. that related to increasing trade between upstream and downstream provinces and to further development of natural resources in the Sichuan/Guizhou/Yunnan region) is assumed to be split evenly between rail and water, while present and projected rail traffic is assumed to shift onto the water mode as follows:

- 25% of steel movements
- 25% of coal movements
- 75% of phosphate movements
- 75% of timber movements

The forecasts for total inter-regional freight and the rationale underlying the modal splits are discussed in detail in Appendix A.

Since it was not possible to reconcile the various forecasts of water-borne traffic, the feasibility study examined the Project at three different projected traffic levels for the year 2030. The Low forecast corresponded to the estimated demand under the CYJV low forecast; the Medium forecast represented the CYJV high forecast; and the High forecast corresponded to the estimates of YVPO, MOC and the Port of Chongqing.

CYJV forecasts of expected passenger traffic on the river, as described in Appendix B, range from 9.0 to $11.6 \times 10^6$ passengers by the year 2030. Based on current vessel loadings, this would result in 20 to 26 one-way passenger vessel movements per day. However, as noted in the Appendix, this may overstate the transits since, with the anticipated growth in
passenger demand, average capacity of the passenger ferries will undoubtedly increase. On the other hand, a significant increase in tourist travel could lead to a smaller average vessel load and an increase in vessel transits.

7.2 Characteristics of Vessel Operations

The construction of Three Gorges Project is expected to cause some significant change in vessel operations on the Upper Yangtze. The key areas of change are as follows:

- composition of the tug—and—barge fleet, with average tow size increasing throughout most of the Upper Reach
- increased daily operating hours
- improved upstream performance due to reduced river velocities

7.2.1 Fleet Composition

The impact of the project on the composition of the tug—and—barge fleet will depend on the level of future transport demand and on the origins and destinations of the traffic. If demand is high and the number of origins and destinations is small, there should be a substantial shift towards maximum—size tows. With lower demand, there may not be any pressure or economic justification to increase average tow—size, particularly if the demand is spread over a large number of origins and destinations. Channel or port limitations at the origins/destinations of some commodities will also affect the composition of the fleet.

With these considerations in mind, possible tow mixes were postulated for each of the forecast traffic levels. It must be emphasized that these hypothetical tow mixes were not optimised either to the traffic or to the characteristics of the channel or navigation facilities. Thus, while these mixes provide an indication of the potential development of the fleet, and of the cost and capacity improvements associated with larger average tow—sizes, they do not necessarily represent the maximum improvement which could be achieved with careful fleet planning and design.

1 Low Forecast (CYJV Low Forecast)

Under the Low forecast, it is assumed that 50% of the cargo tonnage will be carried by CSC. Provincial companies will carry 47.5% and local carriers will handle the remaining 2.5%. CSC cargo will be carried in 6 x 1 000 t tows through the reservoir section. Provincial shipping companies will use 4 x 500 t tows, while local carriers will use 8 x 80 t tows.
2 Medium Forecast (CYJV High Forecast)

Under the Medium traffic forecast, freight tonnage will be split among operators as follows: CSC — 60%, Provincial companies — 37.5%, and local carriers — 2.5%. Within the reservoir, CSC will move 75% of its cargo in 9 x 1,000 t tows and the remaining 25% in 6 x 1,000 t tows. Provincial shipping companies will use 4 x 500 t tows, while local carriers will use 8 x 80 t tows.

3 High Forecast (YVPO/MOC Forecast)

The High forecast traffic will create the greatest push towards larger tow sizes because, unless most of the traffic is carried in 9 x 1,000 t tows or larger, the channel and locks will quickly reach capacity and be unable to meet further growth in demand. (See Sections 7.4 and 7.5 regarding lock and channel capacities.) Accordingly it has been postulated that under the High forecast traffic levels, 80% of the tonnage will be carried by CSC in 9 x 1,000 t tows. The remaining 20% of the tonnes will be carried either by CSC or by Provincial operators in 6 x 500 t tows. This combination makes fairly efficient use of the lock chambers while still allowing for some movement of smaller volumes out of secondary ports.

While the Project will allow the use of 6 and 9—barge tows in the reservoir area, in some cases the reservoir will not extend over the full Chongqing—Yichang reach of the river. Consequently it may not be possible to move large tows all the way to Chongqing. Limitations on maximum tow size are expected to apply through the Tongluoxia and Huangcaoxia sections during FCL season under all FCL scenarios. In addition, it is doubtful whether large tows can be moved through Wangjiatan during dry season in the NPL 150 scenario or through the Sanjiaohai section at NPL 150 and NPL 160.

To overcome this difficulty yet still take advantage of the substantial improvements in river conditions in the reservoir, it is expected that large tows will be operated up to a point near the end of the reservoir. If necessary, large tows will then be broken up into smaller (maximum 3 to 4 barge) tows for the balance of the trip to Chongqing. This "fleeting" requirement will mean a need for additional tugs to move the smaller units and will create some operating delays while tows are re—configured.

7.2.2 Operating Hours

The second operating change attributable to Three Gorges Project is an extension of daily operating hours within the Upper Reach of the river. The elimination of many of the hazards and constraining sections, the generally calmer water conditions and the wider channels should allow 24 hour operation for commercial vessels in the reservoir itself. In the variable backwater reach and further upstream, limits on operating hours
may still be necessary. The extent of these limits will depend on the number of navigation constraints persisting after project completion, which in turn is a function of both season and reservoir level. Assumptions regarding operating hours are detailed in Appendix D.

7.2.3 Vessel Speed/Power Requirements

The third operating change relates to the effect of the Project on velocities in the Upper Reach of the river. As noted in Sections 6.2.1 and 6.2.2, the project will significantly reduce average velocities in the river between Chongqing and Yichang. As a result, upbound tows will be able to travel through the section more quickly and/or using less fuel than at the present time. In addition, the average required power-to-weight ratio for upbound tows will decline thus allowing larger loads. On the other hand, downbound tows will no longer have the benefit of the stream velocity and hence will travel at lower average speeds with potentially higher hourly fuel consumption per horsepower. Again, Appendix D describes the stream velocities and the combinations of maximum continuous revolutions (MCR), speed and fuel consumption which are assumed in the future.

7.2.4 Time Spent in Port

A fourth operating change which can be attributed indirectly to the construction of Three Gorges Project is a further reduction in the time spent in port. Improved vessel loading and unloading times are expected in response to the higher levels of traffic and the larger tow sizes which the Project will encourage.

7.2.5 Impact on Vessel Operating Costs

According to the Vessel Costing Model, the above factors taken together will lead to a substantial decline in average costs of water-borne freight movement. The increase in average tow size contributes most to the saving. However, reduced port times, longer operating hours and lower stream velocities also generate some cost savings. Table 7.1 below illustrates sample costs for CSC movement between Chongqing and Yichang and between Chongqing and Wuhan under different reservoir levels. More detailed findings of the Vessel Costing Model are provided in Appendix D.
THREE GORGES PROJECT FEASIBILITY REPORT

TABLE 7.1 – TUG AND BARGE OPERATING COSTS
– WITH THREE GORGES PROJECT
(fen per tkm)

<table>
<thead>
<tr>
<th></th>
<th>Chongqing–</th>
<th>Chongqing–</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yichang</td>
<td>Wuhan</td>
</tr>
<tr>
<td>6 x 1 000 tonne barges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150/135</td>
<td>1.80</td>
<td>1.33</td>
</tr>
<tr>
<td>160/135</td>
<td>1.71</td>
<td>1.28</td>
</tr>
<tr>
<td>160/145</td>
<td>1.64</td>
<td>1.25</td>
</tr>
<tr>
<td>170/145</td>
<td>1.55</td>
<td>1.20</td>
</tr>
</tbody>
</table>

9 x 1 000 tonne barges

|                      |            |            |
| 150/135              | 1.67       | 1.19       |
| 160/135              | 1.56       | 1.13       |
| 160/145              | 1.46       | 1.08       |
| 170/145              | 1.36       | 1.03       |

By comparison, expected operating costs without Three Gorges are 4.0 fen per tkm on the Chongqing–Yichang route and 3.0 fen per tkm from Chongqing to Wuhan. These costs, however, are based on a maximum 3 x 1 000 t tow (see Section 5.2.3).

While some of the operating changes attributable to Three Gorges may be implemented as soon as the permanent reservoir is established, it is likely that much of the change will be a gradual process. Consequently, the full cost reductions described above will not be achieved immediately. Rather, vessel costs are expected to decline gradually, such that the full cost impact of the Project is realized by approximately 2020.

7.3 Channel Maintenance Requirements

The construction and operation of Three Gorges Project will lead to some significant changes in channel maintenance activity within the Chongqing–Yichang reach of the river. On the one hand, reservoir impoundment will significantly reduce maintenance and operating activity over a substantial portion of the reach. On the other hand, however, the change in hydraulic conditions will alter the level and pattern of sediment deposition, creating new requirements in terms of dredging and river training in order to maintain the navigation channel.

7.3.1 Dredging and Sediment Control

Planning for sediment control is a major aspect of the Three Gorges Project. Numerous studies of sediment deposition characteristics and of measures which can be implemented to mitigate problems have been, and are currently being carried out, using both physical and mathematical
models. A detailed discussion of the sedimentation studies and of the impacts of sediment on the river is contained in Volume 5, Sedimentation. This section highlights some of the findings as they relate to navigation and required maintenance of the navigation channel.

1 Sediment Deposits in the Permanent Reservoir

After completion of the Project, sediment will be deposited both in the permanent reservoir and in the fluctuating backwater reach. In the permanent reservoir area, deposits will accumulate until the reservoir reaches equilibrium state (estimated to occur after some 100 years of operation). However, due to the width and depth of the permanent reservoir and the equilibrium profile most of the sediment deposited in the reservoir is unlikely to interfere with navigation.

Some material is expected to accumulate around the lock approaches and will require dredging once volumes reach levels which interfere with navigation. Model tests indicate that at an NPL of 150 m, dredging would not be required until after 80 years of reservoir operation. At an NPL of 170, preliminary model results suggest an excess deposition in the lock approaches after 30 years of operation. Estimates of the annual volumes potentially requiring dredging at that time range from $80 \times 10^3$ m$^3$ upstream and $280 \times 10^3$ m$^3$ downstream (YSRI) to $100 \times 10^3$ m$^3$ upstream and $354 \times 10^3$ m$^3$ downstream (NSRI). (Volume 5, Section 11.5.1)

These excess deposits can be suction dredged at relatively low cost. In any case, the present value of dredging costs, which will not be incurred until 40 or more years in the future, will not be significant.

2 Sediment Deposits in the Fluctuating Backwater Reach

   — Coarse Material

When the reservoir is impounded, sedimentation will also occur in the fluctuating backwater reach, with deposits of coarse bed load material tending to be concentrated in the upper part of the backwater and finer suspended load sediments tending to be concentrated further downstream.

A large portion of the sediment deposited in the fluctuating backwater reach will have no impact on navigation. In fact, empirical evidence indicates that the navigation channel may even be improved in some areas. However, some of the sediment is likely to accumulate in bars and shoals which could cause navigation problems. Most of the sediment deposits which might affect navigation will be flushed through the fluctuating backwater reach by operating the reservoir at the FCL during the latter part of high flow periods. Coarse material (in the order of 10 mm or larger) cannot be flushed however, and any deposits affecting navigation will have to be
dredged (although river training structures have been proposed to control gravel deposition at some shoals such as Luoqi).

The location of these coarse deposits will be in the upper part of the fluctuating backwater region. Thus, at least initially, most of the deposition will be downstream of Chongqing for the NPL 150 and NPL 160 schemes. With the NPL 170 and NPL 180 schemes, a larger portion of the bed load deposition will occur near Chongqing. Over time, the area of sediment deposition will gradually shift upstream as accumulated deposits in the permanent reservoir cause changes in the hydraulic characteristics, and the nature and location of navigation problems may be altered.

The quantity of coarse material that would be deposited in the fluctuating backwater reach has been estimated in various studies and physical model tests (WCHPRI, 1986) to be in the range of 190 – 225 000 m³ per year. Although much of this may be deposited in non-critical areas, some of it would have to be dredged in order to maintain the navigation channel.

In addition, there will be some coarse material deposited upstream of the fluctuating backwater limit and this will require dredging as it does now. An estimate of this material is not available, but it is understood to be small.

Coarse material can be handled by suction dredging. However, as deposit areas and quantities will vary, and much of the material may be reclaimed for construction materials or granular fill, it would be conservative to estimate dredging costs based on clam dredging. According to discussions with the Yangtze Navigation Administration, costs would be in the order of 20 yuan per m³. If it is assumed that virtually all of the bed load deposits must be removed, annual volumes would be in the order of 200 000 m³, at a total annual cost of 4 x 10⁶ yuan. However, this is a high estimate as it is expected that much of this deposition will not interfere with navigation.

3 Sediment Deposits in the Fluctuating Backwater Reach — Fine Material

It is expected that most of the suspended load deposits in the fluctuating backwater reach can be flushed through by operating the reservoir at low levels at the end of the flood season. Physical model tests indicate, however, that in some areas deposits may accumulate over time which would ultimately interfere with navigation. The timing, location and severity of these deposits varies with different NPL/FCL combinations. (Volume 5, Section 11.6.2) YVPO expects that these problems can be controlled through river training works. River training schemes have been identified for areas downstream from Chongqing (the Luoqi, Qingyanzi, Siguai, and Lanzhuba reaches) where sediment deposits are expected to cause some localized problems with the NPL 150 and 160 schemes.
However, training schemes to control suspended load deposits in Chongqing harbour, which could potentially cause problems for reservoir scenarios with NPL's of 170 and above, have not yet been established or tested. Volume 5, Section 8.6.3, provides details of the anticipated problem areas and the river training works which have been proposed to date.

Because the physical model tests are incomplete and river training not fully specified, it is not possible to establish a consistent and comprehensive picture of the differences among reservoir scenarios with regard to managing suspended load deposits in the fluctuating backwater reach. While it is concluded that these deposits can be managed in such a way that they do not interfere with navigation (Volume 5, Section 11.8), the relative costs under different reservoir scenarios have not yet been determined and cannot be incorporated into the cost analysis.

7.3.2 Winching

As noted earlier, there are currently 12 winching stations in the Upper Reach of the Yangtze which are in operation at various low or high stages of the river. All of these stations are located in areas which will be part of the permanent reservoir under the 150/135/130 scheme and hence also at schemes above these levels. As a result, Three Gorges Project will eliminate the need for winching at all of these locations, thus reducing channel maintenance costs.

7.3.3 Traffic Control

At present there is no centralized, overall traffic control on the Upper Reach of the river. Local traffic control is exercised at the one-way sections on a first-come, first-served basis, and at the Gezhouba locks. Traffic control is based on radio communication and all but the smallest vessels are radio equipped.

Most of the one-way sections and their control/signal stations will no longer be required when the reservoir is raised with resultant savings from the elimination of the structures and the 3–4 man staff at each location. Under all scenarios, however, one-way control will have to be maintained through the Tongluoxia and possibly Huangcaoaxia sections during the flood season. In addition, in the 150 NPL scenario, one-way control stations will be required during the dry season through Wangjiatan and Luoqi.

Given the importance of maximizing hourly transits through the one-way sections, future one-way control stations will probably be equipped not only with radio facilities but also with closed-circuit television and radar. This will ensure that the local traffic controller has the most accurate information to set traffic patterns for optimal capacity and transit conditions.
It is also likely, in the interests of increased capacity, that traffic control systems will be set up for the locks to provide accurate and timely information on approaching vessels. Such a system should be flexible to adjust for vessels that are either ahead or behind their estimated time of arrival so that the locks can be operated efficiently and vessel waiting time kept to a minimum. In conjunction with this, it has been recommended that provision be made to allow waiting vessels to be moored as close as practical to the lock in order to minimize entry time (see Volume 4, Section 10.7.4).

The costs associated with these added traffic control facilities will, to some extent, offset the savings associated with eliminating most one-way control sections. However, the payback in terms of increased system capacity should be significant.

7.3.4 Navigation Aids

The river reach from Yichang to Chongqing is equipped with lighted navigation aids. In most cases the aids are floating, and consist of a lighted marker mounted on a scow type hull and anchored in position. There are also some shore mounted aids.

After the reservoir is raised and the project is in operation, similar aids will still be required. In the reservoir area, the number of aids should be substantially decreased as many shoals and winding channels are submerged. In the fluctuating backwater area and above, however, the requirement for aids would be changed very little.

There are four areas where navigation is reported at present to be restricted to daylight hours:

- km 200 – 205
- km 302 – 311 (at high flows)
- km 485 – narrows
- km 586 – Wangjiatan

While the restriction in the first two areas should be eliminated by the reservoir, the latter two are expected to require improved aids to permit night-time navigation.

In addition to reducing and eliminating navigation aids, the Project should lead to reduced maintenance of floating aids. During the dry season, water levels will be more constant, and in the flood season, the range of levels will be less. This will reduce the amount of work required to keep floating aids "on station" with changing levels. The work can be further reduced by the use of ranges and steering lights where topography and visibility conditions are suitable. This would help to minimize the need for high-maintenance floating aids.
7.3.5 Costs

The main savings in channel maintenance costs associated with the project will come from the elimination of winching stations and the reduction in the number of one-way sections. In addition, it should be possible to reduce the amount of rock excavation and training work which is currently planned for the upper channel. Cost savings will, to some extent, be offset by the increased requirement for dredging in the fluctuating backwater sections. Since the above costs are relatively insensitive to traffic volumes, they have been assumed to be constant over the life of the project.

It is possible that dredging volumes may increase in the later years, but the time frame is sufficiently far removed and the costs sufficiently small that these differences can be neglected from the perspective of economic analysis.

The current annual cost of channel maintenance in the Upper Reach of the river is estimated by the Yangtze Navigation Administration at $10 \times 10^6$ yuan. No official breakdown of these costs is available although the 1985 Preliminary Design Report indicated that annual dredging costs averaged $2.6 \times 10^6$ yuan while winching costs were $0.6 \times 10^6$ yuan in 1982. This leaves a residual of $6.8 \times 10^6$ yuan for operation of one-way control sections and maintenance of navigation aids.

Channel maintenance costs after completion of Three Gorges Project can only be estimated very roughly. Since over 80% of the Yichang-Chongqing Reach (and over 80% of the one-way control sections) are inundated by the reservoir, it has been estimated that 80% of the implied $6.8 \times 10^6$ yuan spent on navigation aids and one-way control stations will be eliminated. In addition, winching costs will be eliminated. However, the $2.6 \times 10^6$ yuan currently spent on dredging will increase to an estimated $4 \times 10^6$ yuan, giving a total annual channel maintenance cost with the Project of approximately $5.4 \times 10^6$ yuan. While there may be some variation in this cost under alternative reservoir scenarios (e.g. NPLs of 170 and 180 should eliminate all dry-season one-way control sections), differences are likely to be small. Accordingly, the same annual maintenance cost has been assumed for all reservoir alternatives.

It was noted in Section 7.3.1 that some river training might be required in order to control deposits of suspended materials. Some of the sediment model tests have indicated potential future problems in some areas if the reservoir is drawn down during a low flow period. However, the timing of these problems is difficult to predict as is the timing and effect of construction of upstream regulating dams which may alleviate the low-flow conditions. Consequently, while the possible need for future river training is recognized, the costs have not been included in this analysis.
7.4 Capacity of Permanent Navigation Facilities

The capacity of the proposed permanent navigation facilities was estimated both separately and jointly using the capacity methodology described in Sections 3.5.2 and 5.3.1.

One of the factors in the capacity calculation is the average number of lockages or lifts per day. This in turn is a function of the "cycle time", which is measured from the time when a vessel begins its entry into a lock until the lock is cleared and ready to accept another vessel. Cycle time rather than transit time will determine the number of vessels which can be passed through the system over a given time period unless, for some reason, it is necessary to clear the flight locks and reverse direction.

While the cycle time is dependent on the elevation change required per lockage or lift, it is estimated that over the range of NPLs being considered (150 – 180) the variation in cycle time is not significant. For the shiplift, the variation in cycle time is estimated to be less than 7%. For the flight locks, the variation is even less since the number of locks changes with the NPL. These variances are probably within the range of accuracy for the lock capacity estimates and certainly within the range of accuracy for tonnes per lockage. Therefore capacities for the locks and shiplift are considered to be the same for the alternative reservoir scenarios.

7.4.1 Assumptions

The assumptions used in calculating the capacity of the permanent facilities were as follows:

- operating time — 22 hours per day, 335 days per year.
- tow mix — varies with demand forecast as noted in Section 5.3.2.
- passenger vessel transits — variable but six passenger vessels represents one lockage or six shiplift operations.
- adjustment for random arrivals — 1/1.3 for the locks and 1/1.37 for the shiplift.
- flow limitation — all navigation on the river will be suspended when flows exceed 56 700 m³/s at Yichang (as compared with 45 000 m³/s under existing channel conditions).

With regard to the average tonnes per lockage or lift, capacities were calculated based on a range of average tonnes for the locks in accordance with the varying tow mixes. For the shiplift, however, the size of the caisson will limit the average tonnes per lift even if average tow sizes on the river increase. Capacity of the shiplift is therefore based on the same vessel mix and tonnes per lift as were used in estimating capacity of the temporary facilities.
7.4.2 Shiplift Capacity

The one-way capacity of the shiplift as a permanent facility, with an allowance for 6 passenger vessel transits per day, is estimated at 6 500 t per day or an annual capacity of $2.2 \times 10^6$ t. It should be noted, however, that this capacity is sensitive to the number of passenger ship transits as shown in Figure 5.4 in Section 5.3.1. If passenger vessel movements increase to equal the number of daily lift cycles (approximately 18), the lift would not be able to handle cargo traffic.

7.4.3 Flight Locks Capacity

The capacity of the flight locks is a function of the lock cycle time and the tonnes per lockage. The lock cycle time can be readily estimated and would not vary appreciably as the average tonnage of the tows changes. The average number of lockages per day, after allowing for non-cargo lockages and adjusting for random arrivals, has been estimated at 16.3 (one-way). The average tonnes per lockage, however, will change with changes in demand and the resulting evolution of the cargo fleet.

Forecasting average tonnes per lockage is as difficult as forecasting demand and indeed the two are related. As demand increases, major commodities would likely be handled by large barges and large tows that would substantially raise the average tonnes per lockage. However, in some cases major cargoes may have to move in small barges due to limitations at the point of origin (e.g. for example, coal coming from mines along the upstream tributaries) and this would restrict the growth of the average tonnes per lockage.

For the temporary lock (240 m x 24 m), average net tonnes per lockage was estimated at 1 700 t, and, for a similar fleet mix, the permanent locks (280 m x 34 m) could be expected to hold about 3 000 t. On this basis, the permanent locks would have an initial annual capacity of some $16 \times 10^6$ t, assuming the shiplift is constructed and able to handle all passenger vessels.

If growth in demand results in a substantial percentage of 9 000 t tows, then the average loaded tonnes per lockage may rise to something in the order of 6 000 t with a resultant annual capacity of approximately $33 \times 10^6$ t. This figure of 6 000 t per lockage, is close to what might be expected given the tow mix suggested in Section 7.2.1 for the Medium (CYJV high) demand forecast.

The fleet mix projected for the High (YVPO/MOC) traffic volumes would result in an average of 7 000 loaded tonnes per lockage, giving an annual capacity (with the shiplift handling all passenger transits) of about $38 \times 10^6$ t.
As noted earlier, however, these fleet mixes have not been optimised either with respect to cargo requirements or with respect to the capacity limitations of the channel and navigation facilities. Thus, while the capacity figures are representative of those which might be achieved through the flight locks, they are not an upper limit.

Achieving higher lock capacities would require that a larger portion of traffic be carried in maximum-size tows. For example, a capacity of $50 \times 10^6$ t per year would require an average tonnes per lockage of some $9\,000$ t, assuming that the shiplift were built and could accommodate all passenger vessels plus some small tows. Provided that very large tows, in the order of $12\,000$ t, come into service, such a figure might be achieved but it would require not only time but careful management of the fleet to achieve such a high average.

### 7.4.4 Total Capacity of Facilities

From the above it can be seen that the major portion of the capacity through the permanent facilities is provided by the flight locks. The shiplift would serve primarily to handle a small volume of cargo and to relieve the flight locks of the need to carry passenger vessels. The total capacity of the permanent facilities, however, is an interaction between:

- the achieved average tonnes per lockage,
- the number of passenger vessel transits, and
- the availability/non—availability of the shiplift.

**Figure 7.1** shows the capacity estimates under a range of assumptions for these three factors. **Table 7.2** below gives the capacities for the tow—mixes postulated under the Medium (CYJV high) and High (YVPO/MOC) traffic forecasts.

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#### TABLE 7.2

ANNUAL ONE-WAY CAPACITY OF THE NAVIGATION FACILITIES

<table>
<thead>
<tr>
<th>Passenger Vessels per Day</th>
<th>Locks + Shiplift</th>
<th>Locks Only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medium Fleet Mix</td>
<td>High Fleet Mix</td>
</tr>
<tr>
<td>0</td>
<td>36.0</td>
<td>41.4</td>
</tr>
<tr>
<td>6</td>
<td>35.0</td>
<td>40.4</td>
</tr>
<tr>
<td>12</td>
<td>33.9</td>
<td>39.3</td>
</tr>
<tr>
<td>18</td>
<td>32.8</td>
<td>38.2</td>
</tr>
</tbody>
</table>
From Figure 7.1 it can be seen that the average tonnes per lockage is a key factor in determining the capacity of the permanent facilities. If the shiplift were to be built, the structure itself adds a rather small amount to the tonnage capacity, but by handling all passenger ships and small tows, it would provide a moderate increase in the overall capacity of the combined system. This effect becomes more pronounced as the number of passenger vessels and the average tonnes per lockage increase.

While the Figure provides a range of capacities that could be achieved by the permanent navigation facilities, it is unlikely, given the probable development of average tow sizes, that the annual capacity will exceed 30 x 10⁶ ts for some time. Higher capacity figures will be achievable only if more large tows come into service.

7.5 Capacity of the Reservoir/River Channel

The capacity of the river channel after completion of Three Gorges will vary with the season, the anticipated reservoir level, and the fleet mix. A detailed discussion of channel capacity is contained in Appendix C. The following sections summarize the findings with regard to the physical limitations of the channel and provide sample calculations of capacity for the fleet mixes postulated under the Medium and High traffic forecasts.

7.5.1 Flood Season Capacity

During the flood season, capacity of the river channel is expected to be limited by the section through Tongluoxia (km 644–645.2) under all reservoir scenarios. This reach of the river will limit tow size and will also, as a result of one-way operations, constrain the potential number of hourly transits. Assuming an average tow size of 2 700 t¹ and a maximum of 4 hourly transits in each direction through the one-way section, the one-way capacity of the river under FCL conditions is estimated at an annual rate of 56 x 10⁶ t, or 14 x 10⁶ t during the 4-month FCL period. With an average tow size of 3 000 t², FCL capacity would be equivalent to 62 x 10⁶ t per year.

Passenger vessel transits reduce this freight capacity as follows:

¹ Average associated with the anticipated tow mix under the Medium (CYJV high) traffic forecast, broken up into 3–barge units to pass through the constraining section.

² Average associated with the tow mix under the High (YVPO/MOC) forecast, broken up into maximum 3 x 1 000 tonne units to pass through the constraining section.
### 7.5.2 Dry Season Capacity

During dry season NPL conditions, the capacity of the channel differs for the various reservoir levels, as various constraints are inundated and new limits apply.

1. **NPL 150**

   At NPL 150, the most limiting section of the channel would appear to be through Wangjiatan (km 582.2–587.7). This constraint applies when water levels are between 146m and 155m. It is questionable whether the full length of this reach would have to be operated one-way at a water level of 150m. The navigation charts of this section suggest that, at higher water levels within the limiting range, it should be possible to sub-divide this reach into two shorter one-way sections, one between kms 582.2 and 583.5, and a second between kms 585.7 and 587.5.

   An alternative limiting section at NPL 150 is the Luoqi reach (km 604 – 606.2). Since one-way operations through this section are required at water surface elevations between 151 and 154.5 m, the reservoir will have no mitigating impact unless flows exceed approximately 6 000 m³/s. On average, flows at Cuntan, which is the nearest relevant gauge, exceed this level approximately 55% of the year, suggesting that for at least 5.5 months navigation would be limited to one-way movements through the Luoqi section.

   If the limiting constraint at NPL 150 is assumed to be a one-way section of approximately 2 km in length, maximum hourly transits would be in the order of 2 vessels each way. With an average tow size of 3 300 t³ capacity through this reach during the NPL season would be equivalent to an annual rate of 34.3 x 10⁶ t. An average

<table>
<thead>
<tr>
<th>Passenger Vessels/Day</th>
<th>Equivalent Annual Capacity (t x 10⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 700 t/tow</td>
</tr>
<tr>
<td>0</td>
<td>56</td>
</tr>
<tr>
<td>6</td>
<td>52</td>
</tr>
<tr>
<td>12</td>
<td>47</td>
</tr>
<tr>
<td>18</td>
<td>42</td>
</tr>
</tbody>
</table>

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Superscript 3: Based on projected tow mix under the Medium traffic forecast, with no provision to break up tows transiting the section.
tow size of 6 400 t\(^4\) would provide capacity equivalent to 66.6 million t per year.

Allowance for passenger transits would reduce these figures as follows:

<table>
<thead>
<tr>
<th>Passenger Vessels/Day</th>
<th>Equivalent Annual Capacity (t x 10(^6))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 300 t/tow</td>
</tr>
<tr>
<td></td>
<td>6.400 t/tow</td>
</tr>
<tr>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
</tr>
<tr>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>18</td>
<td>17</td>
</tr>
</tbody>
</table>

.2 **NPL 160**

At NPL 160, potential capacity limits would appear to be confined to the one—way section at Sanjiaoqi between km 669.7 and 674.3. However, this reach affects only traffic moving upstream past Chongqing to the port at Jialongpo, which is situated at km 672. In addition, the constraint would apply only during part of the winter season when flows in the channel are less than 3 000 m\(^3\)/s. During the balance of the winter season, and throughout the NPL period below Chongqing, hourly transits and hence capacity should only be limited by the required stopping distance between vessels. If one—way operations are assumed between kms 669.7 and 672 for 50% of the NPL season, and unrestricted traffic is assumed during the balance of the season, channel capacity at NPL 160 would range between the capacities through a 2 km one—way section, as given for NPL 150, and the capacity through an unrestricted channel (estimated as approximately 115 x 10\(^6\) t per annum).

.3 **NPL 170 and 180**

At 170 and 180 NPL, the capacity of the river channel will be constrained by the required stopping distance between tows. Based on the expected composition of traffic through the river, their power, length and load, required stopping distances should permit the passage of approximately 115 x 10\(^6\) t per year through the channel.

---

\(^4\) Projected tow mix under the High traffic forecast, with no provision to break up tows transiting the section.
7.5.3 Annual Capacity

The above winter and flood—season capacity estimates were adjusted to reflect the duration of the FCL and NPL seasons, with capacity during the shoulder seasons assumed to be the average of FCL and NPL capacities. This provided a capacity profile over the year under alternate reservoir scenarios. A review of these capacity profiles indicated substantial variations in channel capacity between seasons, particularly for the fleet mix anticipated under the Medium traffic forecast. Since traffic demand would not be expected to exhibit similar peaking characteristics, practical capacity of the channel would be less than the sum of the seasonal capacities. Annual capacities were therefore limited to the lesser of average capacity during two constraining periods or 120% of capacity during the lowest capacity season.

The resultant annual one—way passing capacity of the channel under each of the alternative reservoir levels is shown in Table 7.3 below for the expected fleet mixes under the Medium and High forecast traffic volumes. Capacities were calculated for a range of assumptions regarding daily one—way passenger vessel transits.
Table 7.3 — Annual One-Way Channel Capacity — Alternative Reservoir Levels (t x 10^6)

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Passenger Vessels/Day</th>
<th>Annual Capacity Medium Fleet Mix</th>
<th>Annual Capacity High Fleet Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>150/135</td>
<td></td>
<td>41</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>34</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>28</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>21</td>
<td>40</td>
</tr>
<tr>
<td>160/135 and 160/145</td>
<td></td>
<td>46</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>39</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>170/145 and 180/145</td>
<td></td>
<td>67</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>62</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>56</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>51</td>
<td>49</td>
</tr>
</tbody>
</table>

7.6 Balance Between Capacity and Demand

The above analysis indicates that, under the fleet mixes postulated for the Medium and High forecast traffic volumes, the future capacity of the Upper Yangtze is likely be limited by the capacity of the permanent facilities at Three Gorges.

Table 7.4 below compares capacities of the locks, locks plus shiplift, and channel using 12 passenger vessel transits per day as an example.
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TABLE 7.4 — ANNUAL CAPACITIES —
12 PASSENGER VESSELS/DAY

(\(t \times 10^6\))

<table>
<thead>
<tr>
<th></th>
<th>Medium Fleet Mix</th>
<th>High Fleet Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locks</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>Locks &amp; Shiplift</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td><strong>Channel:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150/135</td>
<td>28</td>
<td>48</td>
</tr>
<tr>
<td>160/135 and 160/145</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td>170/145 and 180/145</td>
<td>56</td>
<td>62</td>
</tr>
</tbody>
</table>

In general, the river channel should be able to handle a greater annual volume of traffic than the lock facilities. The channel limits capacity only at the 150/135 reservoir level when passenger transits are high and the fleet includes a large portion of smaller tows, as in the forecast mix at Medium traffic levels. Otherwise the channel provides similar or greater capacity than the facilities at the Three Gorges.

Under the Low and Medium traffic forecasts, the capacity of the permanent locks would handle projected traffic through to approximately 2035, provided passenger vessel transits are limited to the 18 per day. Under the High traffic forecast, the locks alone would provide sufficient capacity through to 2015–2020 depending on passenger transits, while the locks and shiplift together would meet demand through to 2021–2023.

Meeting the High (MOC/YVPO) forecast demand through to 2030 would require a major effort at optimising the fleet mix. Average tonnes per lockage would have to exceed 9 000 t in order to serve 50 \(t \times 10^6\) t per annum one-way (and would have to exceed 11 000 t if the shiplift were not constructed or was not able to handle all passenger vessels). While these tonnages are within the theoretical capability of the locks, it will be difficult to achieve them. An average lockage of 9 000 t would require that a significant share of the tonnage be moved in tows of 12 000 t or more, presumably with 1 500 to 2 000 t barges. In addition it would mean that only limited space would be available for the smaller Provincial and local tows.
Such a fleet composition is only likely to be achieved if:

- vessel size is controlled by state directives;
- a major portion of the traffic consists of large annual volumes moving between a limited number of origins and destinations; or,
- a lockage fee is imposed which penalizes those tows which make inefficient use of lock space and hence encourages the use of larger tows (for example, a flat fee per lockage irrespective of tow size).

Otherwise, under free market conditions, the low capital cost of small vessels, the ease with which small private operators can enter the market, and their flexibility to serve the smaller ports, will mean that a significant share of traffic will continue to move in smaller units.

If the fleet mix can be modified to achieve better utilization of the locks, the capacity of the upstream channel could become the constraint on the capacity of the system either because of depth restrictions during the NPL season or because of delays in fleeting large barges through the one-way sections during the flood season.

7.7 Evaluation of Alternatives for Permanent Navigation Facilities

The review of demand and capacities described above indicates that, under the Low and Medium traffic forecasts, there is substantial surplus capacity through the navigation facilities for a large part of the planning period. As a result, funds would be spent at an early stage in the Project for facilities which would not be fully utilized for many years.

A number of possible ways for providing a better balance between demand and capacity were examined. Of these, two options appeared to be potentially viable both in terms of technical feasibility and economic benefits. These options were: eliminating or deferring the shiplift; and constructing the permanent locks in two stages, providing a single set of locks initially and twinning later as demand required. The implications of these two options are discussed in the following sections.

7.7.1 Shiplift

Section 5.4.4 discussed the role of the shiplift as part of the temporary navigation facilities and concluded that the shiplift was not cost effective either as a source of additional capacity or as a means of moving goods and passengers during the period when the reservoir was being raised and navigation would otherwise be suspended. The net incremental cost to the system of providing the shiplift ranged from approximately 100 to 300 x 10^6 yuan.

In the YVPO design, the shiplift was also intended to serve as part of the permanent navigation facilities, providing fast transit for passenger vessels and supplementing the capacity of the permanent locks. The evaluation of
the shiplift was therefore expanded to determine whether these functions would provide an economic justification for the construction and operating costs incurred. This evaluation is described in greater detail in Appendix E.

.1 Fast Transit for Passenger Vessels

The average time saving for passenger vessels using the shiplift rather than the permanent locks would be in the order of 2 hours. Assuming that the shiplift operates with a full complement of passenger vessels (18 per day in each direction) throughout the period, the maximum annual value of the time saved would be approximately $8 \times 10^6$ yuan. The annual cost of operating and maintaining the shiplift, including administration and overheads but not including capital cost recovery, is estimated at $3.5 \times 10^6$ yuan. The net present value of a $4.5 \times 10^6$ yuan saving per year over the economic life of the facility is in the order of $12 \times 10^6$ yuan.

.2 Increased System Capacity

If operating at full capacity, the shiplift would be able to serve 18 passenger vessels per day, thus releasing the equivalent of three lockages per day for freight movements. At 6,000 t per lockage, this translates into $6 \times 10^8$ t per year of lock capacity; at 9,000 t per lockage it represents $9 \times 10^8$ t of annual capacity.

Based on the average tonnes per lockage associated with the proposed fleet mixes, the additional capacity provided by the shiplift would be sufficient to meet between 3 and 5 years of additional demand. This presumes that the shiplift is serving a full complement of passenger vessels. If in fact there are fewer than 18 passenger vessels per day, the shiplift's contribution would be lower since its usefulness as a direct means of moving freight is limited by its small caisson. The freight capacity of the shiplift is approximately 700 t/lift. In annual terms, with no allowance for passenger vessels, this represents a freight capacity of just over $3 \times 10^8$ t.

The net present value of the additional lock capacity created by the shiplift's handling of passenger vessels will depend on the length of time required for the system to reach capacity without the shiplift. This will vary for different traffic forecasts and for different assumptions regarding future passenger vessel movements. In addition, it will depend on the extent to which average tonnes per lockage increases to meet rising demand. However, it is unlikely that the permanent locks would reach capacity before approximately 2020 under the High traffic forecast or before 2030 under the Medium forecast of demand. Hence the present value of the shiplift's additional capacity is likely to be small.
3 Conclusion

The long term benefits of the shiplift, that is, fast transit for passenger vessels and increased capacity of the permanent navigation system, and of limited value and would not offset the incremental short-term costs associated with building the structure. Consequently, the conclusion in Section 5.4.4 that the shiplift cannot be justified on an economic basis is unchanged.

7.7.2 Staged Construction of Permanent Locks

As noted in Section 6.1, two alternative configurations were examined for the permanent locks, one consisting of a twin set of four or five flight locks and the other a set of two or three twinned separate locks with intervening channels. Both alternatives were studied by YVPO, and both were judged by CYJV to be technically satisfactory provided potential hydraulic problems could be resolved.

The two alternate configurations were also judged to be similar in capacity. However, under the Low and Medium traffic forecasts, the capacity provided through the locks is well above the forecast demand, particularly in the early years of project operation. Consideration was therefore given to the possibility of matching capacity more closely to demand by constructing only one line of locks initially and twinning at a later date as traffic increased.

1 Feasibility of Staged Construction

The possibility of staging construction of the flight locks was rejected since a single line of flight locks would have less than one-half the capacity of two lines, owing to the time lost in clearing the locks in order to change the direction of transit. A single line of flight locks would also result in long delays. If a downbound vessel arrives at the locks just as an upbound vessel enters the first lock, the downbound vessel must wait for the other ship to clear all four or five locks before it can proceed.

Under the separate locks scheme, however, a single set of locks would have half the capacity of a twin set since upbound and downbound traffic could meet in the intervening channels. Consequently, if demand levels were low, single separate locks would provide a viable means of serving traffic until such time as a second set of locks was required.

From the technical viewpoint, staged construction of separate locks appears viable. The proposed separation between the locks would allow construction on the second set to proceed without interfering with ongoing navigation. In addition, widening of the intervening channels should not create significant interference.
The separate lock scheme does create some operating complications which are not present with flight locks. One complication is the hydraulic problems in the intervening reaches as locks are dumped and filled. This problem can be managed, however, by providing side pondage such that the locks do not dump and fill directly from the channel.

A second operating complication relates to traffic management in the intervening reaches, particularly when lockages are made up of multiple vessels. Trying to keep a number of vessels together as they pass through the channel from one lock to the next could be difficult, and lock cycle times could prove to be longer than anticipated, with consequent reduction in system capacity.

2 Cost Effectiveness

From the economic perspective, the total capital cost of three twin separate locks is estimated by CYJV to be some 21% higher than the capital cost of twin five-stage flight locks. However, a single set of separate locks would cost about 27% less than the flight locks. Summaries of the costs and design criteria are provided in Volume 4, Section 10.6.6. Costs and criteria were based on proposed YVPO designs and arrangements as described in Section 6.1 of this Volume.

If the flight locks are assumed to involve the expenditure of 100 units of money during the Project's construction, the staged construction option would therefore involve the expenditure of 73 units of money during Project construction and another 48 units of money at some later date. If a 10% discount rate is used for capital, the two alternatives would be equal if twinning could be deferred for six years. If longer deferral is possible, staged construction becomes the less costly alternative.

This analysis presupposes that the reliability of the single set of locks is adequate to ensure continued navigation, and that maintenance activity can be scheduled so as not to interfere with traffic. Many river systems in other parts of the world operate effectively using single-lock systems, however, except in areas where flight locks are required.

3 Other Considerations

The cost-effectiveness of staged construction for the permanent locks is dependent on whether twinning can be deferred long enough to offset the added cost of the separate lock scheme; or in other words, whether traffic demand can be handled by a single set of locks for more than six years after the initial stage of construction is complete. A decision on this question at the present time must be based on forecasts of traffic demand 15 to 20 years in the future. While the demand forecasts which have been developed suggest that
staged construction would be cost—effective, they are based on very limited data, and as such are not a valid basis for deciding between lock schemes.

An additional uncertainty relates to the capital costs of a separate lock scheme. The above analysis was based on order of magnitude cost estimates associated with the proposed YVPO separate locks alignment. It is understood that the Ministry of Communications has recently (September, 1987) proposed modified designs for a five—step flight lock system and a three—step separate lock system based on an NPL of 175 m. Cost estimates for these designs indicate that the separate lock scheme would be almost double the cost of flight locks. CYJV has not had the opportunity to review either the designs or the cost estimates in detail, and these revised proposals have therefore not been considered in the above analysis. They are noted, however, as an additional source of uncertainty with respect to the preferred lock scheme.

A final consideration is the impact which the separate lock scheme could have on the construction of the dam and powerhouse facilities. The alignment of the separate locks would interfere with areas on the left bank which are planned for use in siting construction facilities. In addition, the excavation of the downstream approaches would interfere with access to the construction site.

4 Conclusions

While the option of staged construction is technically feasible and could potentially lead to net savings in total project cost, there is substantial uncertainty regarding the forecasts of river traffic and hence uncertainty as to whether twinning of the separate locks could be deferred sufficiently to offset the greater capital cost of this scheme. Because of this risk, the twin flight—lock scheme has been recommended on the basis of its potentially lower capital cost.

Notwithstanding these consideration, it is felt that further analysis and monitoring of potential traffic growth on the river is warranted. If high growth appears improbable and if acceptable design criteria can be devised, the separate locks with staged construction should be considered further. In this case, careful consideration must be given to the potential impact of a separate locks scheme on the construction of the dam and powerhouses.